SOUTHERN CALIFORNIA GEOLOGY

AND

LOS ANGELES EARTHQUAKES

BY

R. T. HILL

This book completely refutes the alarming statement of Professor Bailey Willis that conditions indicate a probability that Los Angeles is due for a severe earthquake shock in the not distant future. It shows that there is no scientific proof that Los Angeles is liable to a severe earthquake shock.

Here are first given by an able scientist in popular language an explanation of the natural causes of our beautiful scenery and charming climate. Southern California is a great out-door geologic museum. The layman is offered a key that will add enormously to his enjoyment of this unique playground; the student of geology or physical geography will find this an indispensable guide.

Published by

The Southern California Academy of Sciences

PRICE FIVE DOLLARS

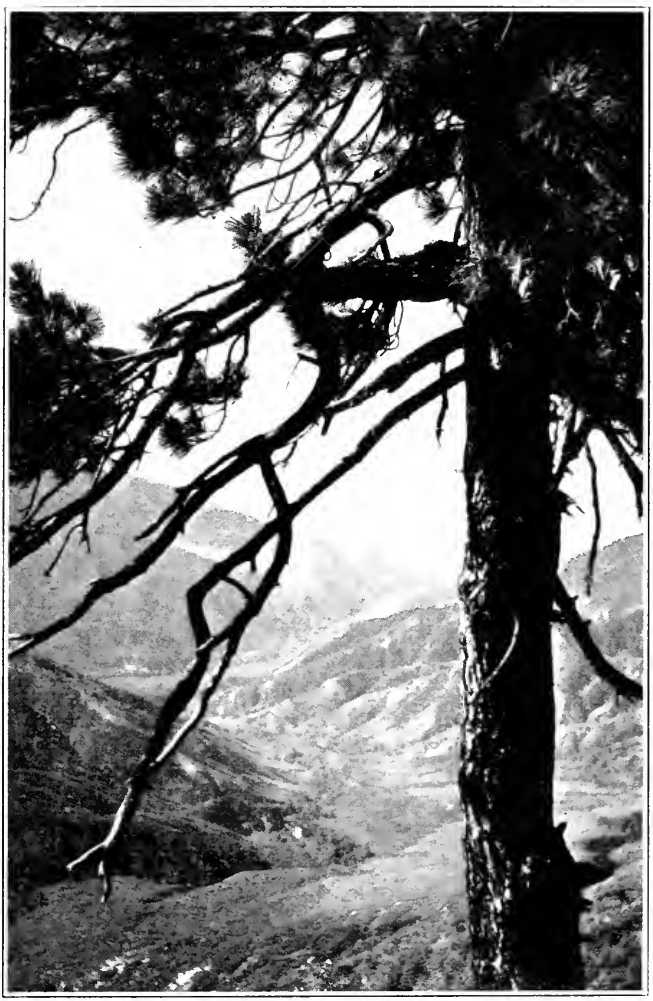
For sale by C. C. Parker, 520 West 6th St., Los Angeles, Calif.

From the collection of the

San Francisco, California
2008

Southern California Geology
AND
Los Angeles Earthquakes

By Robert T. Hill



"RIM OF THE WORLD," SAN BERNARDINO PLATEAU (Palmer Studio)
Scenery produced by down-cutting streams on rising fault block

SOUTHERN CALIFORNIA GEOLOGY
AND
LOS ANGELES EARTHQUAKES

With An Introduction to the Physical Geography of the Region

By

ROBERT T. HILL

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Report Read in Abstract Before the Geological Society of America, Cleveland, Ohio December 30, 1927

Published by the Southern California Academy of Sciences
Los Angeles, California
1928

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PRINTED BY ARTS PRINTING CO., LOS ANGELES, CALIFORNIA

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FOREWORD

This report will embrace brief statements of the general earthquake conditions in Southern California, with reasons for believing that alarming predictions of a future earthquake of great severity are unfounded. Also it will contain a conspectus of some of the hitherto unpublished fundamentals of the geology and physiography of Southern California which give individuality to this interesting country and without which no intelligent concept of the seismologic conditions can be formed.

One step in the undertaking will be to define and describe Southern California, and to show that it is a different and distinct region from the northern part of the State. It is the failure to understand this difference that has in the past caused much misunderstanding.

An attempt will also be made to point out the essential features of the complicated structure of the region, presenting many new characteristics not found in the earthquake map.[1] Space and time will not allow much

[1]Fault Map of California. Compiled from Data Assembled by the Seismological Society of America. Compiled by Bailey Willis and H. O. Wood. 1922. (Place of publication not given). Inasmuch as I was invited to contribute to this map by Dr. Wood, and prevented from so doing by illness. I feel a delicacy in criticizing it. But I cannot refrain from expressing my disappointment at the facts that the relief which was originally depicted with great delicacy and beauty by Mr. Renshawe, was so ineffectively reproduced: that the map makes no distinction between the master and interior faults or their degrees of prominence, and that their conspicuous relationship to the physiography is not shown.

consideration of the rock materials, their nature being for the most part understood.

To comprehend the occurrence and significance of the faulting in California to which the subject of earthquakes is so intimately related one must have an understanding of the broader features of its geography and geology. Inasmuch as the earthquake situation cannot be viewed without this knowledge and as no serious attempt to present the latter has ever been made, I see no other alternative than to at least epitomize the same, as is herein done. This effort has been no small task, as it has involved the assemblage and classification of thousands of observations and the condensation into a few pages of a subject that should fill many.

Furthermore, since I believe that the lessons on geologic history teach us that each relief-shock is a step towards some adjustment or equilibrium and that there is no reason for expecting shocks of increasing seismicity in the future, it will be necessary to present briefly some of the facts of the more recent geologic history.

It seems a curious statement to make in this enlightened age, but the little may herewith included as Plate I, as poor as it is, is the first assemblage and outline presentation of the chief physiographic features of Southern California.

PART ONE

SOUTHERN CALIFORNIA ATTACKED

Basking in the sunshine of prosperity, with its machinery running smoothly and satisfactorily, Southern California has been suddenly shocked, not by one of the occasional temblors that give variety to its otherwise peaceful life, but by the utterances of a geological professor, who, speaking from a position of academic authority, sends forth an emphatic prediction that a great earthquake is soon to take place in Southern California, implying Los Angeles, within a specified time of from three to ten years, and is to be of destructive power like that which afflicted a sister city in 1906.

During the past year, Dr. Bailey Willis, a well-known geologist, went before the Board of Fire Underwriters of the Pacific and also before the National Board of Underwriters in New York and made these startling and alarming predictions. The immediate financial result was the raising of insurance rates in Los Angeles from one hundred per cent to as high as twenty-two hundred per cent. The cost of this advance in earthquake insurance rates has probably exceeded in dollars and cents many times the total losses from earthquakes in California within the period of human history or those apt to be incurred for hundreds of years.

The less direct, and eventually more harmful, effect of the prediction was the dissemination of the dire report throughout all parts of our country and the world; an effect which must, of necessity, be permanently damaging.

The author of these fearsome predictions is a scientific man of standing but in my opinion he has, in this instance, done more to discredit science in the minds of the people of this vicinity than any other incident in recent years. Also, in extending the torch of alarm to interested business he has exceeded the province of a scientific man and an educator.

It is my object in this report to refute his inconsiderate, inaccurate and damaging prophecies. I will show that there is absolutely no foundation for the prediction, either in the laws of nature or the scientific data of this region. And above all I will establish the fact that the whole structure of his prediction is built upon premises which have been disproved and retracted by their creators.

It is my sincere desire that the data herein presented will overtake and cancel the unjust consequences of misinformation.

NATURE OF PREDICTIONS

The following quotation of statements made by Dr. Willis will make clear the nature of his prophecies.

"Indications are that we may anticipate a grave, far-reaching quake in Southern California."

"A great shock may come soon or within a decade, or not until after more than a decade."

"The indications are that we have to expect a deep-seated, more far-reaching earthquake in Southern

California. In the north we have quite a long period to wait."

"These conditions may be interpreted as indicating either little chance of earthquake in Los Angeles and vicinity, or the probability of a severe shock in the not distant future, the latter alternative being of the nature to cause intelligent men to take reasonable precautions."[1]

"I regard it probable that in Southern California there will be a severe shock which is more likely to come in three years than in ten and more likely to come in five than in three."[2]

"I have said to business men, bankers and insurance men connected with Southern California business, 'I would be very conservative in my investment. I would be particularly conservative in the examination of buildings for investment or insurance, and, if I were building, I would see to it that I built right."

He also recommended that the insurance companies should adjust their rates according to the geological surroundings of the properties to be insured—the character of formation and the location relative to fault lines. Inasmuch as some of his followers are now inclined to state that the proximity to fault lines is irrelative, the following words of Dr. Willis should be borne in mind:

"You insurance men will then be able to say, 'You must pay a high rate of insurance because you are near an active fault,' or to another client, 'You do not need

[1]Bulletin of the Seismological Society of America: 1924-25, "Earthquake Risks in California."

[2]This prophecy was definitely repeated in October, 1927.

earthquake insurance because you are not near a fault.' "

His actual predictions as set forth in print[1] were further supplemented by rumors and exaggeration which accused him of saying things even worse than he did say, including predictions that an exact date of June, 1927, was fixed for the disaster. Men and women of the unschooled masses were alarmed almost to panic, and even some of the better informed were greatly disturbed.

For example, early in June the solitude of my study was broken by a phone call from a lady, the wife of a prominent engineer of this city, who, in a greatly agitated voice, wished to know whether it was advisable for her to buy a lot and build a house in Los Angeles, stating that a terrible earthquake had been predicted as being near at hand by a professor of Leland Stanford.

ALLEGED REASONS FOR THE PROPHECIES

It will not be possible, before presenting data, to show all of my reasons for dissentign from Dr. Willis's conclusions, but for the present I can only say that his predictions of approaching disaster in Southern California are largely based upon a theoretical assumption which cannot be verified. By analyzing all of his writings on the subject, it will be found

---

[1]"A Rational Basis of Earthquake Insurance," by Dr. Bailey Willis. Delivered before the annual meeting of the National Board of Fire Underwriters, New York, May 24, 1926.

"Underwriting Earthquake Hazards," by Dr. Bailey Willis. Compliments of the Eagle, Star and British Dominions Insurance Co., Ltd., of London, England, Pacific Coast Dept., Fred S. James & Co., Gen. Agts., 108 Sansome St., San Francisco. Read before the 49th annual meeting of the First Underwriters' Association of the Pacific.

that his postulates are derived from data like the following:

1. Facts concerning the San Francisco quake of 1906 whereby it was learned that the movement was lateral or horizontal along opposite sides of the San Andreas rift.

2. A general inference supposedly "defined by the measurements executed by the Coast and Geodetic Survel," which were supposed to "show that mountain masses are moving through measurable distances." Gaviota Peak for instance is alleged "to have moved twenty-four feet northward in something like thirty years."

"This movement is away from the source of pressure and consequently indicates a growing strain."

3. A theory that the stresses are constant and that relief of any strain by an earthquake at one point along a line of stress is followed by increased accumulation at another. An inference that the "local disturbances of the past eight years in Southern California were regarded as premonitory to a greater one" and that the various small earthquakes of Southern California, like those of Inglewood, San Jacinto, Calexico, etc., have not been sufficient to relieve the strain supposedly accumulating along the southern part of the San Andreas Rift.

4. An attempt by him to create a law of periodic recurrences as is set forth in the Bulletin of the Seismological Society of America for March, 1923: "There was a recurrence apparently of less severity in the early nineties; and these earthquakes of 1918 and 1920 are major incidents of the latest recrudes-

cence of activity. From these facts it follows that earthquake damage is likely to wax and wane periodically and this periodicity should enter into the estimate of insurance as a business matter."

5. An ingenious argument that since the last great "snap" occurred in Northern California the next one is due in Southern California and inferentially at Los Angeles.[1]

It should be borne in mind that all of these postulates hinge more or less upon the allegation that the resurveys of the triangulation points after a long interval by the United States Coast and Geodetic Survey showed that the mountains of California on either side of the San Andreas Rift were sliding past one another at a rate of twenty-four feet in thirty years. **If this allegation, which is the cornerstone of Dr. Willis's structure, should prove to be erroneous, then the remainder of the edifice will tumble. Let us wait and see.**[2]

---

[1]Dr. Willis, apparently forgetting that he had so earnestly and to us expensively predicted that the next great shock comparable to that of 1857 was to take place in Southern California (inferentially at Los Angeles) along the San Andreas Rift, has later and recently made another prediction that a great shock comparable to that of 1857 would take place on the Cuyama or San Andreas Rift to the north of Santa Barbara and extend into the Great Valley, or possibly as far as the Imperial Valley.

As I am writing these lines, November 4, 1927, another large seismic disturbance is taking place in California, one of unusual severity, and of the intensity such as Dr. Willis might have anticipated. But it is not at Los Angeles or other places in Southern California, although we felt its vibration, not even on the San Andreas or Cuyama rifts, or in the Great or Imperial Valleys, not north of Santa Barbara, but to the north and west of it many miles. Its epicenter is on the west end of the East-West extending Santa Ynez rift of the Transverse Fault Group, probably in the ocean near Lompoc and was felt from points fifty miles west of Point Arguello in the ocean eastward to Phoenix, Arizona.

[2]The supposed facts of these pressure-creating movements, which constitute the very foundations of Dr. Willis's predictions were first set forth in Special Paper No. 106, of the United States Coast and Geodetic Survey, published in Washington, 1906, and are fully given and discussed on a later page.

EFFECT OF THE WILLIS STATEMENTS

The essential effects of the Willis utterances were as follows:

1. The arousing of an unwarranted fear in the minds of people in general.
2. The causing of an unjust and undesirable financial burden in the shape of insurance rates to be placed upon them.
3. The propagation of a theory that the times of earthquakes can be predicted.
4. An assertion that the severity of an earthquake may be predicted.
5. The propagation of an unsubstantiated theory of alternations of severe shocks between the Northern and Southern districts of California.[1]
6. The asserted existence of an ever present menace in the shape of a strain-producing pressure from the south northward.
7. An attempted application of the "elastic rebound" and "growing strains" theories to conditions in California which do not exist. In general these prophesies contain predictions of time, place and severity that must all be questioned.

SOME COMPARISONS

That Southern California has been a land of moderate seismic disturbances has long been known. The facts that earth tremors have occurred and that they may often recur hereafter has never disturbed us. These phenomena have been considered of such secondary importatnce as dangers to life and property, that the public, including men of all ranks and professions,

has been content to risk its lives and money here, and, notwithstanding prophecies of disaster, will doubtless continue to do so with a perfect sense of security.

We have been resting in the belief, founded upon a long period of knowledge that, in so far as actual loss of life and property from these quakes was concerned, it had been practically negligible, especially in comparison with the deaths from other natural causes elsewhere in the United States.

So shocking have been the reports of destruction and death in our own country from innumerable tornadoes, twisters, lightnings, floods, and other "acts of God" in the Middle West and on the Atlantic Coasts; among which were the great tornadoes of recent years at Rock Springs, Illinois, the Johnstown flood, the Galveston disaster, the Miami hurricane and the recent St. Louis tornado; that we had come to flatter ourselves upon the security of property and existence. The 1927 tornado at St. Louis destroyed more lives and property in a short time than all the earthquakes of California south of San Francisco have done. We felt that this portion of the state was about as safe a place to live in as could be found in the United States, but Dr. Willis evidently intended to awaken us from this halcyon dream.

PART TWO

GENERALIZATIONS CONCERNING EARTHQUAKES

This paper is not a treatise on the general subject of earthquakes, and hence I discuss the subject only briefly. Volumes have been written about them and the reader who wishes to delve more deeply into the subject can find many books to satisfy his thirst for knowledge.[1]

Modern seismologists hold that an ordinary earthquake is a deep-seated jar to the earth's crust caused when the rock suddenly moves, snaps back, or elastically recoils as a result of release from strain. This is called the rebound theory. In harmony with it, Dr. Daly defines an earthquake as a "snap." Such releases of strains are usually local occurrences, which are associated with earth cracks shown as "faults" or "fault lines," and occur at spots along their extent.

The focus of movement is usually more or less deep-seated and may be several thousand feet beneath where the shock is felt at the surface (the epicentrum). According to Daly, the most trustworthy observations indicate no depths of movement greater than twenty-five miles, the average being not far from half of that.

[1]A good summary of the subject and the associated facts of up-to-date geology, and one which treats of a living world at work, instead of a dead and fossil one, may be found in the recently published work of Dr. Reginald Daly, Professor of Geology at Harvard. It is entitled, "Our Mobile Earth" (Charles Scribner's Sons, Dec., 1926). This work gives in comprehensible English a summary of most that is necessary for the reader to know about earthquakes and seismology.

The pressures or stresses which produce the strains are those incurred by the processes of isostasy, as elsewhere herein described. The sudden releases of strain result from pressure which takes place along the lines of weakness, usually fault lines as above stated. The causes of these movements are not definitely known. They are discussed in another chapter.

Inasmuch as an earthquake is ordinarily the result of a displacement along a limited portion of a fault line, a faut line of magnitude, like the master faults of Southern California, represents the site and results of long series of small earth movements which have taken place successively during extensive periods of past time.

There are other kinds of earthquakes, such as obviously accompany volcanism, that are of secondary interest and need not be described at present. Many students and masters of geology have given great thought to the study of earthquakes and the problems which they present. There is a vast accumulation of literature upon the subject and several scientific societies are devoted to it.

METHODS OF STUDY

Every aspect of earthquakes is being studied at present, including their relations to various phases of nature, such as tides, the earth's rotation, seasons of the year, climate, sunshine, rain and barometric pressure, but the results are foggy, and we still have much to learn.

Seismologic laboratories with elaborate apparatus have been located in various parts of the world. Much has been ascertained concerning earthquakes, but we

have hardly entered into an understanding of the subject.

A laboratorty of this kind is being erected at Pasadena by the Carnegie Institute of Washington and equipment is being installed. Much essential information now lacking concerning the quakes of Southern California will be acquired there during the coming years, under the able guidance of a most competent director, Dr. H. O. Wood. Seismographs are also located at Leland Stanford University and the University of California at Berkeley, and a concerted scientific effort is being made to supply the present deficiencies of knowledge of local earth movements.

The savants of that most unfortunately earthquake-afflicted country of Japan have been leaders in seismologic research, and it is to them that we owe a large part of our knowledge of the phenomena.

OCCURRENCE OF EARTHQUAKES

Movements of the entire crust of the earth are taking place constantly at all times. Its surface heaves up and down slowly, sometimes from uplifts that are nearly uniform over large areas and, again, along narrow belts of folding and faulting. Some parts are rising and others sinking. Nowhere on earth are there more perfect records of such movements of past geologic times as in the rock structure of Southern California.

Earthquakes are usually associated with regions of late mountain-making. There are two great zones of younger mountain ranges. One of these circumscribes the sunken Pacific Basin, including the west coast of North and South America, New Zealand and New

Caledonia. The other extends east-west through Europe and Asia Minor. There is no doubt but that California is included in the first-named group, although seismicity is not so severe on this side of the Pacific as on the other. There are other and older zones of activity in parts of Central Asia, in Palestine, along the Atlantic Coast and down the Mississippi Valley.

All but six per cent of the quakes of the world occur in the two zones first mentioned, and most of these upon the Asiatic side. About four thousand earthquakes are registered each year. Tremors from some of them are felt throughout the earth. Some two hundred or more, mostly too small to be otherwise noticed, were recorded by the instruments at Pasadena in 1923. The latter were small vibrations from shocks throughout the world as well as at home.

SEISMICITY

The liability of a region to earthquake shocks is known as its seismicity. Japan and the east coast of Asia in general is a region of intense and dangerous seismicity. Other regions of the same kind, or even more dangerous, are in Western China and Northern India. History and experience show that the seismicity of Southern California is relatively far less than that of most localities within the great seismic belts of the earth, where shocks, tidal waves and other disasters have occurred of a severity far greater and of more disastrous proportions than have ever been experienced on this coast during the residence of Europeans here. And furthermore, as elsewhere shown, the possibility of such occurrences here is most remote,

as the geologic evidence is that this country has passed the maximum stage of its seismic activity, and is now on the down curve towards quiescence, as will be shown.

THE LINES OF GREATEST SEISMICITY

There are certain great rift lines exposed at the surface along which the great deep-seated shocks become manifest. Such earthquake movements are local and do not simultaneously extend all along the rift line as is popularly supposed. The entire length of the line of faulting may represent the summation of many of these movements which have taken place, little by little, in past times. The entire line along which such movements have occurred may be designated as a line of seismicity.

The San Andreas Rift is usually considered to represent the surface line of greatest seismicity in California. Its path is supposedly a bar sinister which begins somewhere beyond Alaska and runs diagonally across the fair state of California from north of San Francisco to near Yuma, where it crosses the boundary line and continues indefinitely southeast into Mexico. Its landward extent across the State of California, after it comes ashore in Humboldt County sixty miles west of north of San Francisco, is, first, east of south to a point in the Piru Wilderness, some miles north of Ventura, which portion constitutes a division that we herein call the Northern section. From thence its almost rectilinear direction is southeast through Tejon, Cajon and San Gorgonio Passes into the Colorado Desert beyond Banning, and thence on, less definitely, through the Salton Sea towards Yuma, and thence on into Mexico.

There is no way of ascertaining the entire length of the San Andreas Rift. Its total extent may reach thousands of miles instead of hundreds as is ordinarily represented. Further details of this rift are given in a later chapter.[1]

This southeastern portion of its course may for convenience be again subdivided into the Valyermo, Beaumont and Desert Sections. The first mentioned embraces all that part northeast of Cajon Pass. The Beaumont section includes that portion adjacent to the southwest side of the San Bernardino Plateau, while the Desert section is southeastward from the Beaumont section. The course of the San Andreas Rift passes through the centers of population of Northern California. But the Southern California portion of its course lies far to the north and east of Los Angeles and, for a great part, through an unpopulated country. The nearest point of approach of the mostly quiet Valyermo section to Los Angeles is at least thirty miles, and of the more active San Jacinto section some sixty miles.

The portion of this greater line which lies in the bounds of the State of California is known as the San Andreas Rift, and is considered the line of greatest seismicity within the state—a statement which must be modified as will now be explained.

Personally, from long observation and familiarity with the facts, I know that the line of maximum seismicity does not altogether follow the lines above

[1]Several detailed papers and monographs have been written on the San Andreas rift—more than has been written on all of the other great fault lines of California put together. Among these may be mentioned the great monographic work of the California Earthquake Commission. Notably excellent detailed studies and publications have been made in recent years by Mr. L. V. Noble of Valyermo.

set forth, but that after so following it from the northwest to the northeast end of the San Gabriel Mountains near Cajon Pass, it branches therefrom in a still more southeasterly course along the San Jacinto Rift, passing into Mexico near Calexico and Mexicali.

The combined San Andreas-San Jacinto Rift may now be called the chief path of seismicity and, so far as the purposes of this paper are concerned, this line will be meant when we speak of the San Andreas earthquake line in general.

A most important fact about the location of the combined San Andreas-San Jacinto Rift in Southern California is that it does not pass near or in dangerous vicinity to Los Angeles at all, but passes widely around, the nearest point being thirty miles distant. It is not just, therefore, to this city to be placed within its zone of danger as has been done.

The northern section of the San Andreas Rift has attained notoriety for seismicity because the San Francisco earthquake of 1906 occurred along it, and the rift as a whole has been justly or unjustly assigned the reputation of being the line of greatest seismicity in California, along which severe earthquakes have taken place in the past and have been predicted for the future. The reputation of this line located many miles from Los Angeles has even been spread by careless usage to include Southern California and Los Angeles.

It was along the northern portion of the greater line that the San Francisco disaster of 1906 occurred. It is alleged that the earth moved a horizontal distance of twenty-one feet in forty seconds, to the northwest on the west side of the fault line and to the southeast

on the east side of the same, and also where the movement of Gaviota Peak in the Santa Ynez mountains of twenty-four feet in thirty years has been erroneously reported to have occurred. No measurable present-day movements have been recorded from surveys along the southeastern continuation of the line through Southern California, nor have any present-day horizontal movements been witnessed there, although the geologic testimony is to the effect that they have occurred, as is elsewhere herein shown. Shocks have been of comparatively little severity along the main San Andreas fault east of its junction with the San Jacinto fault, where the accumulations and the releases from strain are many. In fact, the number of seismisms along this particular section are no more numerous than those reported in some other parts of Southern California.

Instead of having followed the line of the San Andreas Rift from San Francisco to Yuma, as has been alleged, the greatest seismicity of the Pacific side of California seems to have been largely localized along stretches of three widely different fault lines, to-wit: the northern stretch of the San Andreas Rift, along which the San Francisco and Tejon earthquakes took place; the western end, or Santa Ynez portion of a fault along the north side of the Transverse Fault Belt, to which the Santa Barbara quake of 1924 and the recent Lompoc quake of November 5, 1927, were related; and the San Jacinto Fault, along which the San Jacinto quakes of 1918 and the Imperial Valley shakes of that and other years have been correlated.

Comparatively great shocks have also taken place along the Yuma extension of the San Andreas Rift into

Mexico, notably near Nacosari a few years ago. That well-known site of major shocks in Southern Mexico, the city of Chilpancingo, in the State of Guerrero, is situated in direct continuation with this line.

THE TRANSVERSE LINE

Another line of relatively great seismicity which runs from west to east practically at right angles to the above, approximately along the line of North latitude 34°, 30′, may be termed the Santa Ynez line. This is chiefly marked by a great fault of corresponding directions, which comes on to the land from the ocean near Point Arguello, and continues along the north side of the Santa Ynez Valley as far east as the Topa Topa Mountains. From thence on its course across the Piru wilderness and on eastward has not been traced, but has been inferentially suspected along the Boquet Canyon Rift and through Rabbit Springs Valley, on the east, where it may be looked for on the Desert side and even on into Arizona.

THE LINE OF GREATEST SEISMICITY NOT CONFINED TO CALIFORNIA

It is a mistake to treat of the great fault lines and their associated tremors of the San Andreas, San Jacinto and Transverse zones of seismicity as peculiarly Californian, when they belong to great belts of such lines which pass far beyond the borders of our state to the northwest and southeast, the former from some unknown point at the north towards the Aleutian Islands, southeastward into the West Indian regions, and the later from an unknown point in the Pacific Ocean, probably eastward into Arizona or beyond.

The northern section of the San Andreas zone in California is but the southern continuation of a sub-

marine line which has extended southeasterly along the west coast of North America from the Arctic Circle.

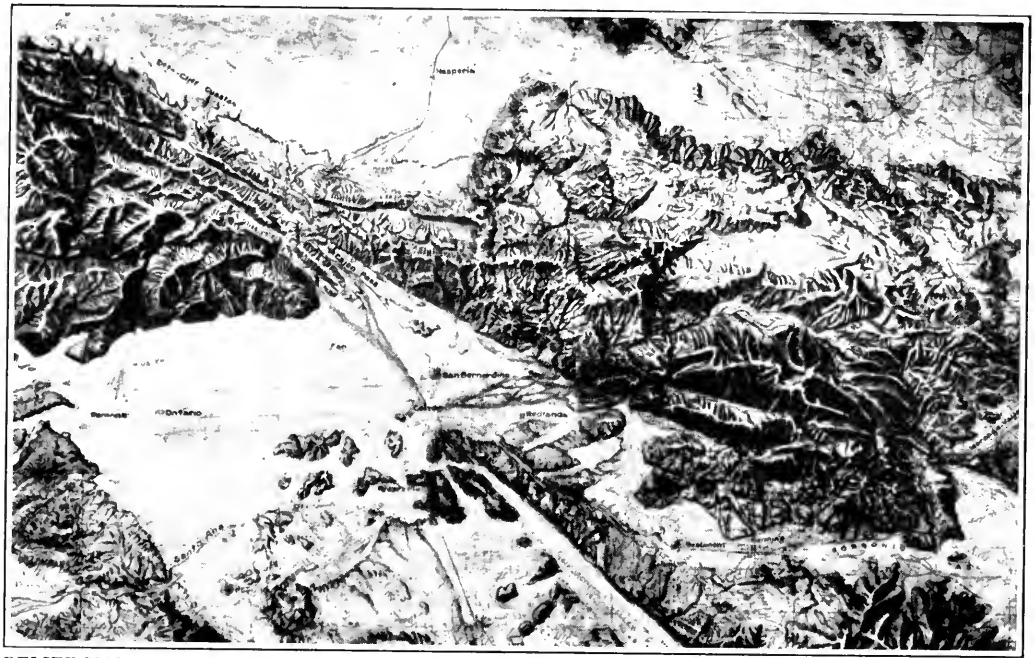
Its continuations southeastward, known as the San Andreas and San Jacinto rifts in Southern California, do not stop at the Mexican border, but extend far onward into the Mexican and tropical regions, where they are present, although the details of their occurrences there are still unstudied. The international boundary is not a physiographic one, as is the great Transverse Structural Belt which separates Southern from Northern California, but these fault lines continue indefinitely beyond it.

SEISMICITY OF SOUTHERN CALIFORNIA

Records of the shakes and tremors which have taken place in Southern California have been made until quite recently without system or scientific supervision, and usually with exaggerated details. In fact, few accurate facts about the quakes of the last century have been preserved.

The knowledge of this subject has suffered from the erroneous policy of concealment of facts at home and from criminally exaggerated reports in the eastern papers. Eastern papers of August, 1927, contain vivid but untrue accounts of "tall buildings dangerously swaying" in Los Angeles at the time of a slight shake early in that month.

Careful research has been made by others to ascertain the earthquake history of California, and their results have been published in the scientific journals. The work along this line has been especially painstaking and instructive. The results may be found in various numbers of the Bulletin of the Seismologic Society of America, particularly the number for June-



RELIEF MAP OF A PORTION OF SOUTHERN CALIFORNIA ADJACENT TO CAJON AND SAN GORGONIO PASSES (RTH)

September, 1916, by Dr. H. O. Wood, who has conscientiously endeavored to give all data concerning selected earthquakes and endeavored to correlate them with the faults associated with the disturbance.

To read his list, which extends from 1769 to 1920, we at first are rather appalled by the number and wide distribution of the quakes recorded. Likewise the comments and notations might not be pleasant reading to the timid minded.

Let me quote the words of Sidney O. Townley:[1] "In 1812 the southern part of the state was shaken by a large number of earthquakes—great damage was done to the missions. For over forty years after this, until 1857, there was not another severe earthquake." On October 25th, 1893, San Jacinto was damaged by earthquakes. "The shocks of 1812, 1868, 1872, and 1906 were most destructive, but we might add that the total loss of life has been insignificant."

There have been several relatively severe tension relieving quakes in Southern California since 1906. These were principally along the San Jacinto branch of the San Andreas rift line, at San Jacinto, at El Centro, Mexicali and elsewhere. One series of shocks also occurred at Inglewood and several small ones in Los Angeles.

There has also been a severe and property-damaging shock at Santa Barbara in 1924, but this occurred near the Santa Ynez fault line of the Transverse or East-West System, and did not affect Southern California and the Los Angeles region in general.

There is much evidence to show that the severities of the tremors of 1769, 1812, 1857 in Southern Cali-

[1]Bulletin of the Seismological Society of America 1919.

fornia were greatly overestimated. At least such is the fact in regard to stories about some of the old missions. The falling of the tower of the old adobe mission church at San Juan Capistrano in 1812 (29 persons having been killed thereby) and of adobe houses at Yuma and Tejon in 1857, are the outstanding earthquake disasters of Southern California. In each instance, the buildings of adobe mud were inferior in construction, without proper reinforcement, if any, and of crushing and tensile strengths so low that one wonders how they sustained the weight of their own walls. The facts of history seem to be that it was the bell towers of the old missions that tumbled, and these were extraordinarily unstable, mud structures. At least such was the case at San Juan Capistrano and probably when "the bells of San Gabriel were shaken down."

A significant fact in this connection is that, as a result of the repeated rain-storms of February, 1927, the foundation of the tower of the old mission of San Luis Rey were disintegrated to such an extent that it also fell, without aid of any earthquake vibrations. Fortunately, no worshippers were present to be killed.

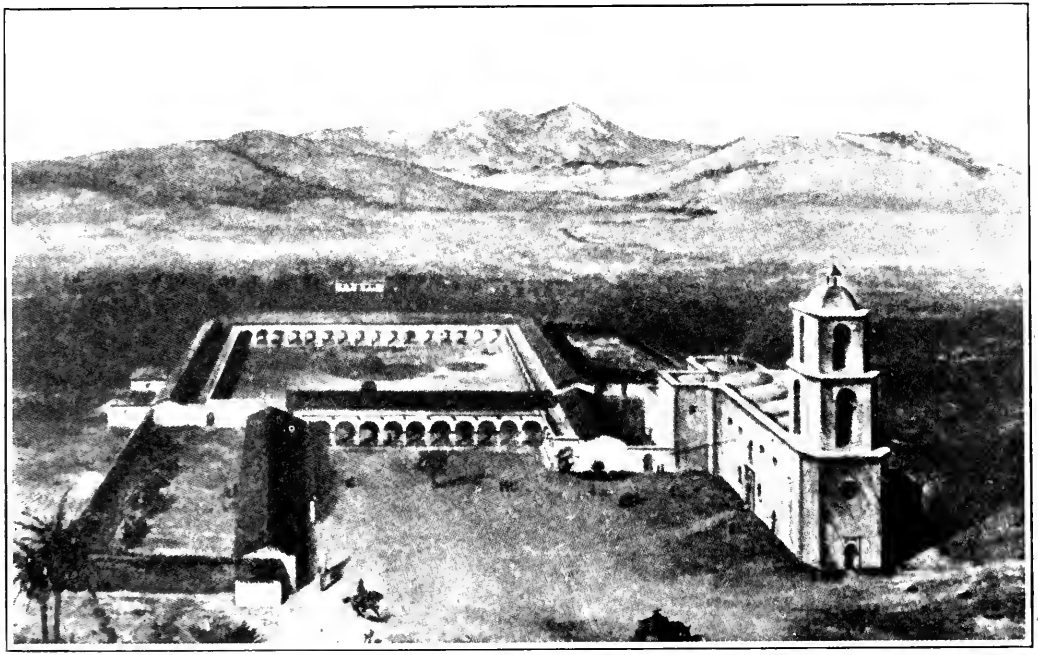
Mr. John Gaffey of Los Angeles states that at the San Juan Capistrano Mission there was originally a tower which had become weakened by the action of the elements and that this was shaken down through the roof during services at the time of the earthquake of 1812, causing numerous deaths—the greatest loss of life from all the known earthquakes of Southern California.

A recent survey of the ruins of this mission by the writer makes him wonder how the structure as orig-

inally built ever stood at all. Its architecture was expressed by an extravagant use of wide spanned, unstable arches, such as have been known to endure for centuries in Spain and Morocco, where good lime, cement and stone abound. On the other hand, the San Juan Capistrano Mission was built of inferior, unburned bricks and triangular, soft-sandstone sprawls, laid in limeless mud which by no stretch of imagination could be called mortar. Surmounting the structure which was 175 feet long, whose roof was already weakened by the fanciful addition of seven poorly constructed domes, was a slender tower 100 feet high which fell upon the roof and demolished it and twenty-nine people beneath it. The whole structure was so fragile that the vibration from any passing truckload of today would have demolished it, for it was a veritable house of cards. Father Junipero's original church adjacent to the one destroyed, and better built some fifty years before, stands next door, today as perfect as ever.

Equally strong testimony that these quakes were not extraordinarily severe is the fact that the mission church buildings at Los Angeles and San Gabriel which were not shaken down were situated upon alluvial soil, which is considered to be dangerous as a foundation material by some people. The perfect condition of preservation of these structures proves incontestably that no known tremors in Southern California have been of sufficient power to seriously injure them, much less to destroy them.

It is a common thing to hear of the great destruction wrought at Inglewood in 1920. It has been called that "most serious and damaging disaster," while the truth of the matter as we have heard



THE FATAL TOWER OF SAN JUAN CAPISTRANO MISSION
From an old print

it from two reputable eye witnesses is that a part of one building only was thrown down, and that this was the false, brick-front of a house of wood, without any binding between the two structures whatsoever. The affair invited destruction from the least vibration that might disturb its equilibrium, and it was a wonder to all who saw it that it could ever have stood at all.

We are greatly indebted to Mr. J. B. Lippincott and Mr. John Gaffey for information concerning the old structures of the region. The latter, who is an old and respected citizen of Los Angeles well versed in its history and traditions, has said that in so far as he knows the Church of the Angles at the Plaza has never been injured by an earthquake, nor has the San Gabriel Mission. Both buildings are in excess of one hundred and twenty-five years old. He also states that there are many interesting old houses of the Spanish period still standing in the Los Angeles region which testify to the general safety during much of the time that earthquakes have been recorded in Southern California. A number of these old houses from eighty to one hundred years old may still be found north of the Plaza and on New High Street. The Camulos house, near Saugus is one hundred years old. The former Sepulveda Mansion at San Pedro, built in 1840 and taken down in 1913, was never injured by an earthquake. The Dominguez mansion, some eighty years old, has also never been inqured.

Nothwithstanding the evidence above presented Dr. Willis asserts that the last great shock in Southern California was in 1857, or seventy years ago. He called

it a "terrific shock," an "extraordinarily severe shock which produced great release of strain" and one which "affected all the region from San Juan Bautista in the latitude of Monterey Bay down to the Salton Sea." The line so described is that of the San Andreas Rift, which as we have shown, does not run through Los Angeles. It is possible that the whole fabric of his ingenious theory of disaster is founded on this erroneous association of the course of that line with the location of our city.

THE LOS ANGELES CITY REGION ONE OF MILD SEISMICITY

There is no positive proof that a serious earthquake has ever taken place in Los Angeles. In all the history of Los Angeles, there is no record of a good building having been thrown down or a person injured by an earthquake. This is saying a good deal in view of the fact that some of the flimsiest buildings ever constructed have at various times been built in the city.

Concerning the severest and best observed quake we have had, that of July 16, 1920, the center of which may have been somewhere near First and Alvadaro, the record shows that only "the plaster was cracked and globes broken." When considered in the light of the fact that the origin was within the well-built, city area, the damage was slight indeed.

In spite of the endeavor to pass the trouble along to Southern California, the fact remains that the greatest earthquake movement in California of historic times was that of the San Andreas rift in 1906 at or near San Francisco, where, it is stated, that for a short distance the west side of the fault, to a depth of four or five miles, moved horizontally northwest twenty-one feet in forty seconds.

ARTISTIC BUT UNSAFE MASONRY DETAIL,
SAN JUAN CAPISTRANO MISSION

DIFFERENCES BETWEEN THE SEISMIC CONDITIONS OF NORTHERN AND SOUTHERN CALIFORNIA

The geologic and geographic differences between Northern and Southern California, which are reflections of the relative earth movements, are very great. These are pointed out in a separate and later chapter. Some of these have an important bearing on the question of their relative seismicity. Among them may be mentioned:

(1) The positions of the great centers of population relative to the master and active fault lines and the abyssal escarpments. Students of diastrophism will understand the significance of such conditions without the necessity of my dwelling upon them.

(2) The positions of the centers of populations near or distant from the immediate strand line. The importance of this is due to the fact that the weight and moisture of the advancing and receding tidal waters may sometimes be the force that pulls the seismic trigger.

(3) The testimony of the changes of level which have taken place in the respective localities within recent time.

Both coasts show evidences of elevations and subsidences in later geologic time, as well as differences in geologic materials. The southern coast and islands show evidence of late Pleistocene and Recent elevation, over 1100 feet in all. The comparable part of the northern coast in the vicinity of San Francisco apparently shows greater subsidence during the similar time.

The San Andreas line of maximum seismicity extends close to and into the border of the sea in Northern California, especially near the cities of San Francisco and Palo Alto, where Dr. Willis' residence and experiences have been.

In Southern California the San Andreas and San Jacinto rift-lines lie from fifty to two hundred miles inland and pass for the most part through thinly settled regions. I believe that all analyses and comparisons that can be made between these conditions in the two regions will prove immensely favorable to Los Angeles.

DIFFERENCES IN MATERIAL

The many points of differences of detail between the geologic material and structure of Southern and Northern California have great bearing upon the question of earthquakes and, when considered, will be found to be of great importance.

Dr. Ralph Arnold has recently called attention to these differences in a telegram to the Los Angeles Chamber of Commerce which we use by his consent. It is as follows:

"I believe persistent rumors that Los Angeles is due for disastrous earthquake are absolutely unfounded. Those scientists who are apparently taking this view have less practical field knowledge of conditions in Southern California than I have. Our greatest menace in California from earthquakes is through the San Anderas rift. This is at least 40 miles north of Los Angeles, separated from it by great buffer range of granite mountains. Our quakes result from movements along local faults which, being in soft Tertiary beds, reach a breaking point with much smaller stress than along San Andreas Rift, hence we may expect earth-

quakes more frequently but of much less intensity than those along the rift, especially when it involves the harder rocks such as granite and the Franciscan and Cretaceous formations."

If the great stresses arising within the zone of flowage are deep-seated, and directionally far-reaching along the line of weakness as they apparently are, then the nature of the veneer of a surface of sedimentary rocks may soften but not cancel the movement. But this cushioning may be a great protection value, as Mr. Arnold shows.

GEOLOGICAL FORMATIONS OF LOS ANGELES NOT UNFAVORABLE

The alluvial formations of this city, especially the old sediments of the Los Angeles river, which underlie the business part of city are well settled, more or less compact, and ordinarily dry, unlike the ocean-water-saturated alluviates of San Francisco harbor with which they have been erroneously compared. The facts that the oldest houses of the region and the Los Angeles and Santa Barbara Missions are built on such formations and have withstood all historic shakes of the region, sufficiently negates the idea of the instability of its old, alluvial formations.

DIFFERENCES IN STRUCTURE

There is no identity between the fault systems of Northern and Southern California, except in the instance of the supposed continuity of the San Andreas Rift from one region to the other, which the path of maximum seismicity is supposed to follow, and which, as I will show, may be a line of several united faults.

In Northern California the fault pattern and con-

ditions of the Pacific side are entirely different from those of Southern California and especially from those of the Los Angeles region (See Plates I and II). It is utterly unjust to classify them together.

Examination of the earthquake map of California by Dr. Willis shows that along a long and narrow coast belt adjacent to the city of San Francisco[1] there are depicted no less than ten closely spaced parallel faults,

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[1]Notes on the structural geology of San Francisco (compiled). The Bay of San Francisco is a submerged valley. If uplifted it would resemble Santa Clara or Santa Rosa or Napa Valley. The present maximum depth of the Golden Gates is 49 fathoms. The average depth of the bay proper is 4-8 fathoms.

In the San Francisco area the general trends are northwest-southeast. There are three orographic blocks:

The Montava Block is on the west, through which pass the Pilarcitos and San Andreas fault lines. This block is separated from the Marin-San Francisco block on the east by the San Bruno Fault. The Haywards and related fault zone separates the Berkeley Hill block from the Marin-San Francisco block.

San Francisco-Martin and Montara Blocks have suffered recent depression but the Berkeley block shows cut terraces with recent fossils—this is along the margins of San Pablo Bay. Since Quaternary time the Marin peninsula between Bolinas and San Francisco Bay has been depressed, thus allowing the flooding of the lowered—net result being an uplift. Point Reyes peninsula has been uplifted about 250 feet and then slightly depressed. San Francisco peninsula shows slight subsidence.

The main fault, San Andreas rift, is about eight miles from the city of San Francisco proper. It passes to the west under the ocean. All the belt of faults practically belong to the San Andreas zone.

The San Bruno fault is about five miles southwest of the city. This line of fracture is older than the San Andreas. It is paralleled on the northeast by another fault zone which is nearer the city about half a mile. The San Bruno fault joins the San Andreas near Bolinas Bay. The Haywards fault is about eight miles to the northeast of this line, and there are many faults both thrust and normal.

The Haywards fault line is younger than the one along the base of the Berkeley Hills along which the original uplift took place. It may hold the same relationship to this older fault that the San Andreas holds to the San Bruno.

The San Andreas is a live fault. So far as it is notable in the area the movement has been more horizontal than vertical.

There are many minor faults in the San Francisco block, one of which extends southeast through the city. There are several faults that cross the main trend of the blocks. In the Berkeley Hills one passes down through Strawberry Canyon (lying back of the campus.) Movement along this line has placed the Quaternary beds against Cretaceous.

The present population of the so-called metropolitan area lives around San Francisco city and county, Oakland, Richmond, Berkeley, Alameda, and parts of Contra Costa, Marin, and San Mateo counties which are adjacent. The present metropolitan area might be said to include the district within fifteen miles of the Ferry Building. The East-Bay region has fifty per cent of the land area and forty per cent of the population. The metropolitan area of the future it is said will cover a district within a forty-mile radius of San Francisco. Insurance payments after the San Francisco fire were said to equal $225,000,000.

of which almost all are marked as "probable" live faults. These lines all belong to one directional fault group, instead of to five or six widely separated ones as do the faults of Southern California. The system to which the northern faults belong is that of the Second Northwest Group and specifically the San Andreas zone, as described in the later chapter of this paper, although individual names are there given to its several members. This narrow zone of faults close to the sea constitutes the line of maximum seismicity in Northern California. (See Plate III.)

The several faults of Northern California are in general parallel to the seashore, instead of being widely separated and distributed throughout a cross-section of three hundred miles as in Southern California. Furthermore, the zone or belt in Northern California lies closely adjacent to the seashore and not far from the abyssmal scarp, in positions where the earth movements are more liable to occur than if they were inland, while the City of Los Angeles and most of the fault lines of Southern California lie at considerable distance from the sea.

Owing to the narrowness of the northern zone, its proximity to the sea and the nature of the geologic materials, the stresses are apt to be concentrated along it, and the relief shocks which accompany them are relatively more severe.

In Southern California, on the other hand, as will be shown in the next part of this work, the fault fractures belong to, at least, four distinct ages and directional systems, which are widely distributed throughout a width of over two hundred miles. They also cross one another so that the fractures are checker-

boarded in mesh-like arrangement, and the movements of strain-relief are diminished and distributed accordingly.

The faults of the second northwesterly-extending group of Southern California are quite different in details of arrangement from those of the same group in the San Francisco region. Instead of being closely spaced within a belt a few miles in width, as at San Francisco, they occur as nine or more widely-spaced master rift-lines upon the land, each separated from the other by less-rifted zones of about twenty-five miles in width, and the whole group distributed throughout a belt of two hundred and fifty miles or more. These rifts in Southern California extend in southeast directions for one hundred and fifty miles from the proximity of the Great Transverse Belt to the Mexican Boundary and from thence on into the Republic of Mexico for indefinite hundreds of miles. Names and locations of the fault lines are given elsewhere herein.

EARTHQUAKE DANGERS EXAGGERATED

The vast majority of earthquakes in California are harmless and most of them take place unnoticed. They are mostly the growing pains of a living world at work. Their percentage of danger is exaggerated and their few casualties disproportionately feared. Of all the so-called "acts of God"—storms, tornadoes, hurricanes, tidal waves, hot spells, floods and freezes—they have caused less destruction of property and life in the United States of America than any of the agencies mentioned. More people are killed annually from accidents to buildings caused by faulty construction than

have ever been killed in our history from collapses of buildings during earthquake shocks.

Several times the atmospheric vibrations from the firing of big guns of the navy at target practice off San Pedro have caused more damage in the shape of window-breaking and chimney-shaking than all of the earthquakes of Southern California have ever done.

From the admittedly imperfect statistics gathered by Wood and others and published in the Bulletins of the Seismological Society, we gather that about 170 shocks have been recorded within historic times (since 1780) in Southern California, none of which have been productive of human fatalities or serious property injuries within the city of Los Angeles, or extensive similar damages elsewhere in Southern California.

From a study of these statistics I temporarily infer that these may have been accredited to the various fault lines as follows:

San Jacinto Rift, 92; San Andreas Rift, 16; Elsinore Rift, including the lines past Pomona, Corona, Murietta, Elsinore, Pala, near Julian, etc., 16; Inglewood, 14; Los Angeles City, 2, and some 30 uncorrelated shocks from distant localities.

Likewise, many of the shocks which take place along the San Jacinto and Santa Ynez lines are felt with greatly reduced intensity in Los Angeles, which is some seventy miles distant, and are often accredited to local movements within that city.

Many of the small shocks felt at Los Angeles are vibrations from distant epicenters. For instance, at 5:49 and 5:52 A.M., on the morning of November 4, 1927, the day when this was being written, the writer

noted two prolonged shocks which vibrated his bed very appreciably. He even thought it was a temblor which might have been on the Inglewood or the Los Angeles City faults, and he telephoned to Eagle Rock, Inglewood and other nearby points for reports, but none came which testified to any more severe effects than we had experienced in the heart of the city. Later in the day the press reported that the epicentrum was probably between Surf and Honda, a few miles southwest of Lompoc and some 150 miles northwest of Los Angeles. It was interesting to find in the fine type below the fear-creating headlines that the damage done was "one chimney shaken down and one plate glass window broken." And the next column told of great floods in New England and India, where countless lives and houses were destroyed.

While some of these shocks, especially those along the San Jacinto rifts in 1893 and 1918 may have been moderately severe and destructive to very poorly constructed buildings, there are hundred of thousands of intelligent people living in California who experienced most of them and who do not look backwards upon them with any harrowing recollections, nor have they any fear in their minds of their future recurrences.

The important deduction from these statistics is, that while a few mild shocks may be of nearby origin, most of the temblors felt in Los Angeles are diminished vibrations from more or less distant fault lines—principally the Elsinore, the San Jacinto and San Andreas rifts—yet no one of them has ever caused serious disaster. Another important deduction is, that the vibrations of the shocks along the San Andreas line of seismicity has seldom been felt in this city. The

reverberations of the great Frisco shock of 1906 were hardly noticeable here.

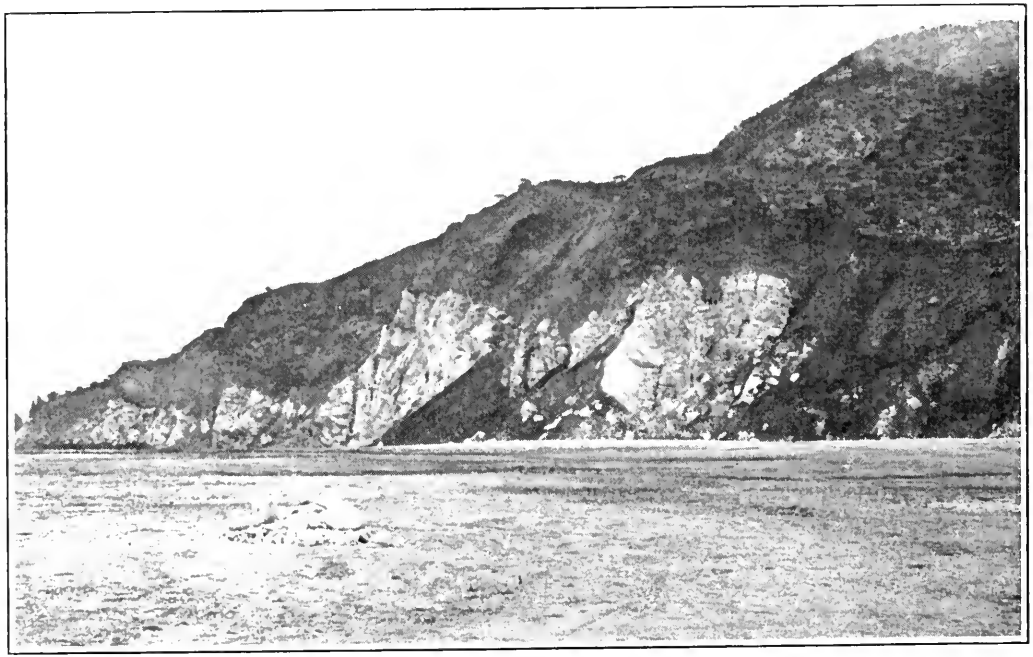
RELATIONS OF FAULT LINES TO DANGER

The majority of earth shocks of Southern California are supposed to occur at points along certain definite and well-determined fault lines, the locations and histories of which are more fully described in a later chapter on the geologic structure.

Townley has written that "investigation has shown that, except when a building was located right on a fault or very near a fault line, **none of the earthquakes of the past 150 years have been strong enough to seriously damage a well constructed building.** In the San Francisco earthquake, the steel and concrete class A structures were not seriously damaged and neither were well-constructed brick and frame buildings." He also says, "the San Andreas, San Jacinto and Elsinore faults are, fortunately, so far from Los Angeles that earthquakes originating along them lose much of their intensity by the time they reach the city."

Willis himself has stated that "if you are on the fault, the danger is extreme. If you are ten or twelve miles away, the danger is very materially less." Certainly the longer distance of Los Angeles from the San Andreas, San Jacinto and Santa Ynez rifts greatly lessons our dangers from them. I believe that the statistics prove incontestably that the San Jacinto fault line, the nearest point of which is sixty miles from Los Angeles, is the most active fault line in Southern California, and that the seismicity of Los Angeles is comparatively very low.

Local shocks sometimes occur in Los Angeles from



FAULT LINES IN LIMESTONE QUARRY NEAR RIVERSIDE

the minor faults within its limits or at its doors. There is no recorded reason for suspecting damage from them. It has also been stated that only horizontal movements are destructive. If this statement be true, then it is a reaffirmation of the fact that the San Andreas line is the chief one about which to be concerned.

RELATIONS OF EARTH MOVEMENTS TO THE ABYSSAL ESCARPMENT

Although the ultimate seat of earth movement is known to be far below the ground and we have treated the San Andreas Rift as the site of the greatest surface manifestations, the great Abyssal scarp which constitutes the outer edge of the Continental Shelf (see Plate I) may be looked upon with suspicion as a site of probable faulting and other dangerous movements. For this reason the great seismisms have largely been phenomena of submarine faults near the sea shores. Kingston, Santiago, Lisbon, San Francisco and other places have been examples. There are notable exceptions of course.

There are many logical reasons why this should be. The oscillations of tides, the depositions of marginal sediments are disturbing adjustments of load.

Los Angeles, instead of being situated near or upon the immediate edge of the Abyssal scarp, is over one hundred miles away from it, twice as far from it as is San Francisco.

TESTIMONY OF THE INGLEWOOD FAULT LINE

The one possible fault line of the Los Angeles vicinity upon which suspicion might be cast is the Inglewood fault line. This is associated with the Domin-

guez Range and practically parallels the coast from Westgate, east of Santa Monica, southward towards San Diego. Some of the light jars and tremors which have disturbed the tranquility of Los Angeles in the past may be accredited to this line of movement and one of them in 1920 caused considerable attention.

Past performances along this rift do not justify alarming predictions as to its future. The Inglewood shake of 1920 and possibly the Capistrano shake of 1812 may be attributed to movements along it. In the first instance cited no dire results followed, and the falling of the poorly constructed tower through the church roof at San Juan Capistrano has been explained on another page. One can see that it would have taken but a very minor tremor to have shaken this building down. The rumbling of a modern truck or the vibrations from the firing of a great naval gun would have done it, had the tower existed today.

The fact that the elongated fold of the Dominguez Range, which is cut throughout its length by the Inglewood fault, has retained its stores of oil and gas for thousands of years might be interpreted by some to indicate that the shocks along this line have never been sufficiently great to open fractures for their escape. Oil and gas in such pools are very volatile substances, and are quick to leak out through any fracture in their natural containers. These were perhaps the most perfectly locked-in oil pools ever found in the State.

Judging from past history, it cannot be said that there is any great menace from the Inglewood line. Its releases from strain have consisted of small vertical movements, sometimes frightening, sometimes slightly damaging, but at no time seriously dangerous.

EARTHQUAKE DAMAGE IS LARGELY AVOIDABLE

It is neither my intention nor desire to minimize the dangers of earthquake disasters such as have taken place in other parts of the world where conditions of greater seismicity than here have prevailed, but to whose severity those of California are in no ways comparable, as cited by Daly. It can be truly said that the great casualties of time past have been due to conditions which could have been avoided by proper structural and geological considerations. Thus it was that the greater number of deaths at Tokio were from the hurtling of the heavy roofing-tiles through the air; at Messina from the fact that the walls were composed of thick and poorly-cemented, rounded boulders with unfastened joists. The property destruction at Santa Barbara resulted from poor construction in general and from the fact of the location of the city upon the site of an active fault line.

There is no evidence in all the seismic history of Southern California of a properly constructed building having been shaken down or wrecked by an earthquake. Even in the instances of the severe earthquakes at San Jacinto, we are informed by one of the highest class contractors of Class A buildings in Los Angeles who visited the vicinity after its greatest quake in 1918, that only buildings of most inferior and deficient construction were destroyed. A prominent architect of this city in a recent lecture before a private club of distinguished membership, asserted that he believed that not a single, well-constructed building was injured by the Santa Barbara quake of 1925.

SEISMIC CONDITIONS ARE PROBABLY DECLINING

It is my opinion that earthquake conditions are becoming less severe in Southern California, and if such things could be quantitatively determined, it would be found that the region is in the declining curve of a great seismic cycle. Both the surface geology and physiography, as shown in other portions of this report, show that the time of great movement was principally in the Pleistocene epoch—the great Ice Age—and we are living in a time of decreasing earth movements, whose tendencies are towards the compacting of the strata to geologic stability and temporary quiescence.

These movements, although still somewhat in evidence, are not going on today at the rate which they did in the past nor are they apt to increase in the future.

If these hypotheses be true, it also appears to us that the present-day shakes are merely the lighter after-effects of a former time of greater movement during the Glacial Epochs, rather than the virile manifestation of a new cycle of activity. Therefore it is improbable that the earthquake-snaps in Southern California are going to increase in severity in the immediate future or attain the magnitude that they did in the Pliestocene epoch of the past.

It is probable that some fifty thousand years from now the down curve of the movement towards quiescence may cease, and then they may begin to increase again. But what may happen to the human race by that time no one knows.

WHY THE PREDICTIONS WERE UNWARRANTED

A just criticism of Dr. Willis's predictions can be made to the effect that their language conveys the impression that Southern California is a region of maximum seismicity where major shocks like those which have occurred in Eastern Asia and elsewhere may take place. None of them states the fear-relieving fact, as I now emphatically do, that no such intense degrees of seismicity are known to have occurred or are expected to occur here on the eastern side of the Pacific Basin, as are now known on its western, or Asiatic side. Earthquakes of as great severity and destructive capacity as ever known in California have taken place in the mid-continent and Atlantic sea-board regions—Boston, Charleston and New Madrid. Therefore, it is obviously wrong to inculcate impressions upon the minds of the people at home or abroad that we are in any unusual earthquake danger. When interrogated upon this subject one of the leading earthquake authorities admitted the truth of this statement, that the property loss was the chief concern, and that proper construction would avoid even this loss.

COLLAPSE OF THE PREDICTION OF ALTERNATE OCCURRENCES

One of the weakest of the erroneous postulates is that inasmuch as the last, large, relieving seismism along the San Andreas rift had taken place in Northern California in 1906 that the next one must, necessarily occur in Southern California.

This prediction was made upon the further theory that since the last, relieving shock in Southern California was in 1857, and a later release was in North-

ern California in 1906, another snap was soon due here, owing to the "accumulation of strain."

Arguments were presented at some length to show that such a shock could not take place north of San Francisco along this line of seismicity (which extends in that direction to the Arctic Circle); arguments which have been thoroughly refuted by the major quake which took place in the sea off the Alaska Coast, October 24, 1927.

If the seismic snaps, or releases, are to take place alternately between the northern and the southern ends of the San Andreas alleged line of greater seismicity according to Dr. Willis' theory, and the next one is to take place to the south, why should the latter necessarily take place in Southern California, which embraces only one hundred and fifty of the two thousand miles along which the line extends in that southerly direction?

It is like sitting in the main offices of the great Southern Pacific Railway System in San Francisco and prophesying where the next spike will loosen or the next train will be derailed along its thousands of miles of track. Especially does it now seem absurd since the recent, major shocks of 1927 off the coast of Alaska, at Lompoc and in the Cholume Valley.

Since the collapse of the former, mountain-movement theories, as explained on another page, there are no data to establish the theory that such alternations of occurrences might take place in California.

In order to arrive at laws of alternations, periodicity and recurrence of shocks along this line we must not only consider the insufficient history of earthquake occurrences in California, but their occur-

rences throughout the length of the line of seismicity from the Arctic Circle to near the equator, and the width of the belt from the ocean depths beyond the great abyssal escarpment across the Continental Shelf and the Pacific and Desert sides of California into Arizona and New Mexico. Concerning such history we possess practically no data whatsoever.

It is evident that a deduction to the effect that the next great shock along the line of seismicity should necessarily take place in Southern California rather than at any other point along that 8,000 miles between the Arctic Circle and Venezuela is preposterous.

The present and future line of interest in earthquake studies pertains to the great stresses and the elastic strains resulting from them. Analysis of all of Dr. Willis's writings show that he had assumed that he possessed data of this kind concerning the Pacific side of California which are not in existence and which were both the corner stone and foundation of all his predictions.

WHY OUR EARTHQUAKES CANNOT BE PREDICTED

Two questions concerning earthquakes naturally arise. These are, first, if there are laws of rythmic or periodic recurrence, and secondly, if there are means of predicting such occurrences.

It is the hope and aim of every geologist that methods will be devised for ascertaining a manner of predicting the periodicy of the shocks of every earthquake zone, but they have thus far not been discovered.

We do not and cannot deny the general principles of geology which hold that earthquakes result from the

releases of strain along fault lines. Seismologists have been strenuously striving to ascertain methods for predicting the place and time of future earthquakes with a hope that laws of periodicity of recurrences of shocks along fault lines might be established in countries where they have been more sufficiently studied, as in Japan or Italy. The best authorities agree, however, that such methods have not been perfected, and that such advance along these lines as has been accomplished, required the accumulation of more and better data than we have acquired in the past in California.

OPINIONS OF OTHERS

Milne has said, "Ability to herald the approach of these calamities would unquestionably be an inestimable boon to all who dwell in earthquake-shaken countries, and the attempts which have been made both here and in other places are extremely laudable."

Dr. Daly has truly said[1] that "fairly elaborate plans are already worked out for measuring earth strain which develops as the years go on. It may take a generation or more to accumulate sufficient data for the purpose of forecasting the place and, less probably, the time of earthquakes." Arrangements are now being installed for such measurements in California.

It is true that earthquake centers may have migrated from time to time, as in Italy, along the lines of a great fracture where they occur, and that some students of earthquakes in countries long under observation have concluded that there are periods of maximum occurrences of shocks along certain given

[1]Our Mobile Earth, 1927.

fault lines, of which the history and the exact locations of the previous occurrences of shocks are known.

It is not to be denied that in some regions the rhythm and periodicity of stresses and strain relief has been sufficiently determined to permit some approximately accurate predictions. Cotton has noted that "Hayes and Lawson predicted with some success the Mexican earthquake of 1907 and Omori has shown by his prediction of the Valparaiso and Formosa earthquakes how, in a very general way, it may be possible within rather wide limits, to approximate both time and place of earthquakes. He has also pointed out that in a number of cases there is an increase of seismic activity preceding a disastrous shock."[1]

DR. G. K. GILBERT'S OPINION

The words of the late Mr. G. K. Gilbert, one of America's most eminent geologists, upon this subject of earthquake predictions constitute a pertinent and correct summation of the whole subject.[2] He states that efforts to solve this problem have been connnected with: (1) rhythm, (2) alternation, (3) idea of trigger or starter, (4) prelude. All the above lines of approach are worthy of consideration. The questions of rhythm "are based on two ideas, (a) that any region having a hard shock is immune for a period of years or decades, (b) that after the first destructive shock of any earthquake the danger is over. Neither of these have proven out in practice in all earthquakes." In connection with this subject he also says that "It is not

[1]Cotton, L., "Earthquake Frequency and Tidal Stresses," Bull. of the Seismological Soc. of America, June-Sept. 1922.

[2]Science, Jan. 22, 1909.

at all true that either the great shocks or small shocks affecting a particular locality . . . are separated one from the other by a regular or approximately regular interval; and it is not true that the immediate danger is past when a great shock has wrought its havoc; and yet I am prone to believe that the rhythmic principal does hold a place in the mechanism of earthquakes."

". . . . And if it were possible to group the shocks according to place of origin it might be found that each earthquake center has its orderly law of sequence. But while the existence of such a systematic arrangement seems within the range of possibility I regard it as altogether outside the field of probability and I feel sure that any attempt to discriminate rhythmic series on numerical grounds without any other basis for classification would prove unprofitable."

"The hypothesis of alternation between parts of any district is being tested—but the verdict belongs to the future. Hypothesis of precipitation by accessory forces, which are in a large part periodic and foreknown, has a good status and is being developed on the statistical side. It promises to make the time of prediction more precise if ever the approximate time shall be obtained by other means . . . The hypothesis of an intelligible prelude has only been broached and the manner of testing it is not yet in sight . . . In a word, the determination of danger-districts and danger-spots belongs to the indefinite future. . . . If the places of peril are definitely known, wise construction will take all necessary precautions and the earthquake-proof house will not only insure itself but will practically insure its inmates."

FUTILITY OF ATTEMPTS TO ASCERTAIN LAWS OF PERIODICITY IN CALIFORNIA

Such meager data as we possess concerning California seismicity has been closely scanned in hopes of ascertaining some law whereby future earthquakes may be predicted, and several attempts to discover laws of periodicity have been made. But alas, the seismicity has been too slight and the records too incomplete for coming to satisfactory conclusions.

If data were as abundant and running through the centuries in California as in Japan, Italy, and Palestine, or if we had but one rift-zone upon which to blame the individual quakes, prediction might, to a degree, be possible.

Willis has concluded that there is an interval of about thirty years between the maximum shocks in Northern California, and he has probably had this in mind in his prophecies concerning Southern California, for he fixes the date of the next great release in this part of the State as about three to ten years from now, which would be about 30 years since the San Francisco earthquake of 1906.

Townley states that the shocks of 1812, 1857, 1872, and 1906, concerning all of which except the latter the data were very incomplete, were the most destructive. The intervals between these are forty-five, fifteen, and thirty-four years. Not much rhythm in that. He also notes that for forty-five years after the earthquake of 1812 until 1857, there was not another severe one.

Others have deduced an approximately 50-year period from the fact that the greater California

earthquakes have taken place in the years of 1769, 1812, 1857, and 1906, which were 43, 45, and 49 years apart respectively, or an average of about 46 years. But there is no proof that the shakes mentioned were the most severe. The two or three similar instances may have been the merest coincidences.

The wide divergence of opinion exhibited by these estimates only tend to confirm one of the main theses of this paper, that too little study has been made and too little is known of the history of earthquakes in Southern California to form conclusions on the subject of periodicity.

FOREBODINGS NOT SHARED BY MOST GEOLOGISTS

Fortunately, the opinions of Dr. Willis are not shared by many geologists and many of the best are on record in writing as distinctly of the contrary opinion. In fact I know of no one who is fully in accord with him, and even a few who were at first inclined to follow him will recant when they read the proofs of the error of his ideas which are given on a later page. Gilbert, Branner, Lawson, Arnold and others on record stated that no such disasters as suggested need be anticipated nor can be predicted. Over a hundred geologists of high standing live in Southern California, who go about their business without fear or anticipation of disaster, many of them in homes built quite near or on the fault lines. Of two chief students of the allegedly dangerous San Andreas rift in Southern California, one lives almost directly on it and the other has constructed a beautiful mansion near the Verdugo fault line.

Concerning the subject of the possibility of prediction of future shocks in Southern California, we also refer the reader to the words of Mr. H. O. Wood, California's leading authority upon seismology:

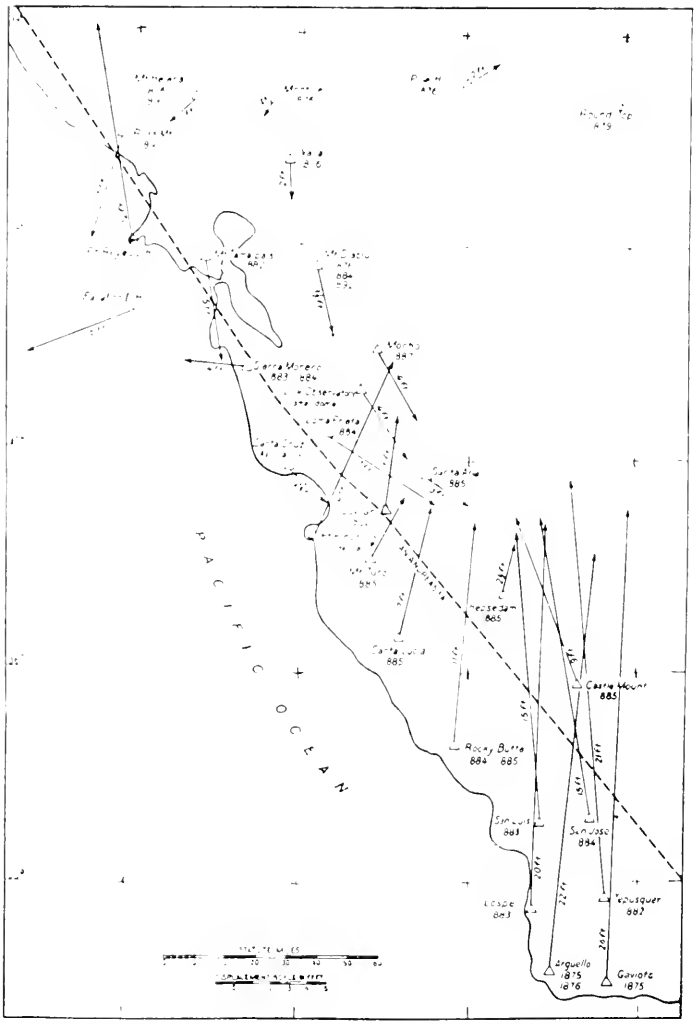
> "I desire to state at the outset that the best that I, or any other person, can do in this matter is to form a careful judgment based upon the available facts, which in many respects are scant and ill-coordinated. There is no definite or exact knowledge regarding the earthquake situation in the future, here or elsewhere, in the possession of any student of this subject. Competent and reliable men may reach somewhat different conclusions on the basis of such facts as are available. Notwithstanding this, certain conclusions are warranted, and others are not. In particular, no one can say that a strong or destructive earthquake is certain to occur in Southern California within a definitely specified short interval in the future, nor that such an event is very probable within such a definitely specified short interval. Such a pronouncement is a definite prediction—unwarranted in the present state of knowledge—and even if it should be verified by the course of events this at best would only be the confirmation of a shrewd guess. . . ."

FUNDAMENTAL DATA PROVED TO BE ERRONEOUS

The layman may not have clearly comprehended it, but the entire structure of Dr. Willis's theories and damaging predictions were founded upon certain deductions from reports of the re-surveys by the United States Coast and Geodetic Survey of its triangulation points situated upon high mountains in California. These observations were made at intervals of years before and after the San Francisco earthquake of 1906, as reported in its Special Publication No. 106, Washington, D. C., 1924, entitled "Earth Movements in California," by William Bowie, Department of Commerce, Serial No. 203.

The report shows certain astounding results to the effect that the positions of stations in the Coast Ranges between Santa Barbara and Santa Cruz on the west side of the San Andreas Rift had changed northward at various rates from four to twenty-four feet in the past thirty years, and that ten or more stations east of the rift had changed southward on an average of about four feet. The differences were between results of old surveys made from 1851 to 1899 and new surveys made after the San Francisco earthquake from 1906 to 1922.

These results, as shown in Plate VI, were astounding for, if true, they suggested as has been quoted from Dr. Willis that "mountain masses are moving measurable distances along either side of the San Andreas fault line." Gaviota Peak, for instance, was reported to have moved northward twenty-four feet in thirty years. This supposed movement was inter-



VI. Plate From Paper 106, U. S. Coast Survey Which Suggested the Alleged Movements Along the San Andreas Rift

preted by Willis to have been "away from the source of pressure" and "consequently to indicate a growing strain from the southwest"—the one whose future release was to produce the great earthquake predicted for Southern California within "from three to ten years."[1]

From these admittedly questionable data he deduced that the strains supposedly resulting from this great stress, pushing from the south, had been relieved in Northern California by the San Francisco shock of 1906, but as further supposed by him, the pressure was still active and the strains were still accumulating in Southern California along the line of the San Andreas Rift since the quake of 1857. Upon this latter supposition he reached the deduction that the next release of strain was due in the latter region. The time factor in his predictions was arrived at by deductions from his concept of a thirty-year cycle of periodicity based on the few and unreliable earthquake data in existence concerning California, as stated.

Under the impression that the Coast Survey's findings as announced in 1924 in Special Publication 106, were true, some few geologists believed in the substance of Dr. Willis's deduction that the strain which

[1]In justice to the Coast Survey, as called to my attention by a recent letter from Director Jones of that organization, it must be said that Special Paper 106 warned the reader that the apparent changes in the position of the stations should not be accepted as positive evidence of earth movements.

Following is the letter from Director Jones:

"I should like to call your attention to the statement, in Special Publication No. 106, carrying a warning against accepting the difference in geographic positions shown on the diagrams as being due to earth movements. It was not known at that time whether the changes were due to earth movements or to the unavoidable errors of triangulation which had not been rigidly adjusted."

had been released to the north by the San Francisco quake of 1906, might be still accumulating to the south, but few if any of them agreed with him that the site of the next release could be specifically in Southern California within a definite time limit, between three and ten years from now, or that it would be of undue severity.

Alas! even the deductions of Science are not infallible, for as I will presently show the very fundamentals of the above theories have been discredited by the fact that the Coast and Geodetic Survey, which after re-computation of the figures previously given, has announced that instead of having moved twenty-four feet to the north in thirty years, "the new position of Gaviota Peak is approximately four and a half feet southeast by east from the old one" and that "the changes in position reported in Bulletin 106 were due to triangulation errors and not to actual earth movements except for some of the stations." See Plate VII.

THE COAST AND GEODETIC SURVEY REVISES ITS DATA

During the past year the writer had heard rumors to the effect that the Coast Survey had questioned the accuracy of its own determination as above stated, and had for some time been engaged in recomputing the data. On October 26, 1927, it occurred to him to send a telegraphic inquiry to the Survey at Washington for the exact facts. The telegram as sent and its responses of startling importance were as follows:

Los Angeles, Oct. 26, 1927.

Dr. W. Bowie,
U. S. Coast and Geodetic Survey,
Washington, D. C.

Please wire me a night letter stating time and amount of movement of Gaviota Peak and other localities along San Andreas Rift and how far determinations are dependable. Regards.

Robert T. Hill.

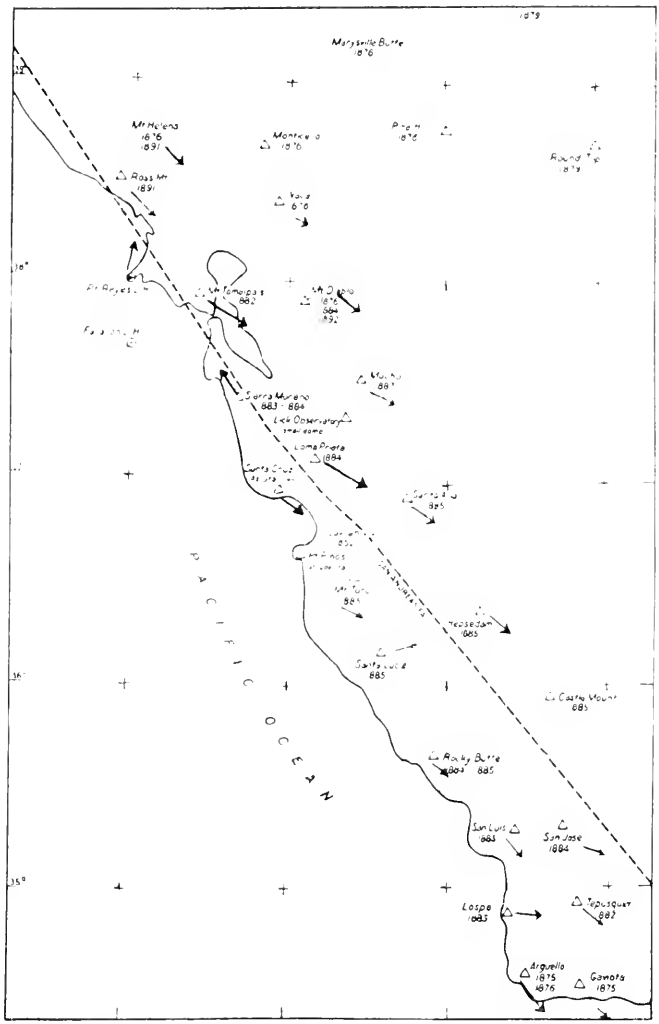
1927, Oct. 27, PM 3 53
Washington, D. C., Oct. 27.

Robert T. Hill,
Los Angeles, Calif.

Readjusting old work strengthened by the Laplace azimuth shows less movement than preliminary results indicated. Gaviota five feet southeast old position, but other stations in vicinity show changes to southward varying from two to six feet. Owing to great length of arc involved no definite indication earth movement south of Mount Toro. Letter follows.

Faris,
Acting Director Coast and Geodetic Survey.

The subject matter of the response was unexpectedly astounding. Instead of confirming a movement of Gaviota Peak of "twenty-four feet to the north in thirty years," such as constituted the foundation of Willis's theory of the accumulation of great pressure, whereby Southern California and Los Angeles were to be endangered, it showed that the movement had not been over five feet and was in an opposite direction. It also showed that there were no definite evidences of movement in Southern California at all!



VII. Compilation of the Revised Data of the Survey Which Cancels the Previous Determinations

The foregoing telegram from the Coast and Geodetic Survey of date October 27, 1927, was followed by receipt of the letter therein mentioned.

Department of Commerce
U. S. Coast and Geodetic Survey
Washington

October 29, 1927.

Dr. Robert T. Hill,
Los Angeles, California.
Dear Sir:

Enlarging upon the information sent you in my night letter dated Oct. 27, I wish to say that since the first comparison was made of the geographic positions of triangulation stations in California, resulting from the work done in the field thirty or more years ago and that done in the last few years, a complete readjustment of the triangulation net of the western half of the country has been made. That net was controlled by many Laplace azimuths and base lines, with the result that the adjustment shows great strength in the various sections of the net.

I am enclosing a copy of our serial No. 350, which gives a brief account of the net adjustment which, I think, will interest you. Under separate cover there will be sent you a copy of No. 134. The closing errors of several loops, shown in figure 8 of the latter publication, indicate very clearly the accuracy of the triangulation in the western part of the country.

The old geographic positions in California resulted from triangulation in which no Laplace azimuths had been used. A Laplace azimuth, as you no doubt know, results from observations on Polaris corrected for the deflections of the vertical at the point where the obser-

vations were made. This deflection of the vertical is obtained from the difference in the longitudes determined by astronomic positions and by triangulation. Where Laplace azimuths are available, the triangulation can be held rigid in direction. Without such stations, there is a swerving of the areas of triangulation from their true course.

In order that the western half of the United States might have its triangulation of the requisite strength, a number of Laplace stations were established in California, during and just after the triangulation observations were made. These Laplace observations were available for the readjustment of the triangulation done some years ago.

The new triangulation was extended to the eastward of the stations Mt. Lola and Round Top, on the crests of the Sierra Nevadas, to stations in central Nevada. A comparison of the angles in the new work and the old and of the geographic positions of several stations indicates very clearly that there has been no shifting in position of the stations Mt. Lola and Round Top and those to the eastward. The triangulation stations to the eastward of Cuyamaca and San Jacinto, extending to the Colorado River, were reoccupied in the last few years. The original observations across Southern California were made about 1910. The comparison of the angles and positions between the new and old work for that triangulation across Southern California indicates conclusively that no earth movements had occurred in that region or, at any rate, that there was no relative movement among the stations involved.

Since no changes were indicated in geographic positions to the eastward of Mt. Lola and Round Top and of

Cuyamaca and San Jacinto, it was decided to use those four stations as base stations in comparing the old and the new triangulation in California. In the adjustment of the old work, the geographic positions of Mt. Lola and Round Top and of Cuyamaca and San Jacinto, which resulted from the western net adjustment, were used as bases for the observations of the old triangulation. The results obtained would indicate a change of geographic position of about six feet to the southeastward for Mt. Tamalpais, nearly four feet northward for Sierra Morena, seven feet southeastward for Loma Prieta, and varying amounts—less than seven feet—for the stations between Loma Prieta and Gaviota. The directions of change in the positions for the intermediate stations are generally southeastward. There is a southeastward movement indicated for stations Mt. Helena, Monticello, Vaca, Mt. Diablo and Mocho, varying from approximately six feet at Mocho to three and one-half feet at Monticello.

Adjustments are now being made at this office of additional stations such as Mt. Ross, Farallones Lighthouse and some stations in the vicinity of Monterey Bay. The results are not yet available.

To the eastward of Gaviota, the differences in positions vary from one foot to five feet. The general direction of change is southeastward to the vicinity of the stations Santa Clara and Laguna. There the direction is more southerly and, when we get to Mt. Wilson and the Los Angeles base stations, the direction of change trends to the southwest.

Since the arc of triangulation extending from Mt. Lola and Round Top to San Jacinto and Cuyamaca is about 500 miles in length along the axis of the scheme

and since we cannot depend on an accuracy in geographic positions of much more than one part in 150,000, it is seen that a change of one foot in 30 miles is most likely due to errors of triangulation. This would mean that, in 150 miles, a change of four or five feet would probably be due to errors of triangulation. The new position of Gaviota is four and one-half feet approximately southeast by east from the old one.

The change in direction and amount of the new geographic positions from the old ones, resulting from the latest adjustment, from what occurred when the preliminary computations were made a few years ago, has not been thoroughly analyzed by this office. This will be done in the immediate future and it is hoped that a publication setting forth the results will be shortly forthcoming. In any event, the latest results seem to indicate that the changes in position (reported on in special publication No. 106, "Earth Movements in California," a copy of which is enclosed) were due to triangulation errors and not actual earth movements, except for some of the stations. I have in mind the ones to the southward of Mt. Toro and Santa Ana, where there seems to have been a progressive movement to the northeastward.

As soon as we have anything more definite than what is given above, I shall communicate with you further.

Very truly yours,

(Signed) R. L. FARIS,
Acting Director.

A possible ambiguity in the next to the last paragraph from which it might be inferred that the mountains south of El Toro and Santa Ana had moved

slightly to the northeast, will be made clear by reading the telegram. The outstanding points of this letter are as follows:

1. The new position of Gaviota Peak instead of being twenty-four feet to the northward is four and one-half feet, approximately, southeast by east from the old one. Note well that this negates the alleged movement to the northward of Gaviota Peak twenty-four feet in thirty years, as alleged by Willis, and cancels his deductions that there is a growing strain and earthquake producing pressure from the south to the north.

2. A change of four or five feet would probably be due to errors of triangulation, and is not dependable.

3. The comparison of the angles and positions between the new and old work for that triangulation across Southern California do not indicate conclusively that earth movements occurred in that region, or, at any rate, that there was any relative movement among the stations involved.

4. In any event the latest results indicate that the **changes of position reported in Bulletin 106 were due to triangulation errors and not to actual earth movements, except for some of the stations.**

Thus the foundations upon which were built the whole structure of Dr. Willis's predictions of disaster in Southern California have crumbled, bringing down all of the superstructure with it.

PART THREE

SOME ESSENTIALS OF THE PHYSICAL GEOGRAPHY OF SOUTHERN CALIFORNIA

One reason why the earthquake conditions of Southern California have been so little understood and so misrepresented is because the essential facts of its physical geography and geology have never heretofore been properly presented. This entirely different region has been treated as if it were an integral part of Northern, or older, California, when, in fact, it has but few relationships to it, as will be shown.

Modern-day geologists and geographers have interested themselves in many things foreign, but the fact remains that some salient features of our own country remain unmarked and undescribed. These remarks apply particularly to the regions around about us here in the Southwest, including many of the great highlands and valleys of Eastern California and of Northern Mexico.

CALIFORNIA IN GENERAL

Beauteous land of natural wonders! The recreation ground of a nation, the paradise of all nature lovers, the outdoor laboratory of geologists and other scientists delving at its secrets, which sometimes seem doomed never to be understood!

What newcomer, who has seen its peculiar highlands and valley plains, its eccentric rivers, its detached islands and its terraced coastlines, but has wondered why such things are, as they are, so different from features elsewhere seen.

Although called a portion of the Pacific Province of the great Cordilleran Region of the United States—that newer, western half of our continent, so contrastingly different and foreign to the older, eastern, or Appalachian half—the State includes several distinct sub-provinces, each of which is worthy of being considered as a geographic unit.

Yes, all of California is different from the remainder of the United States, from the New England and Appalachian States, from the mid-continent plains and prairies, the Rocky Mountains, or other regions. Even within its bounds its several parts are different from one another, and of these parts Southern California is different from all the rest. It will be excusable in me to classify and briefly describe its divisions in a manner somewhat unlike that which has heretofore been done.

CHIEF SUBDIVISIONS

Including the Continental Shelf, the features of the State may be broadly classified into six great groups: (1) On the Desert Side, to the north, a portion of the Great Basin Region whose further extent is eastward into Nevada and Utah; (2) to the south, on the desert side the Gulf of California or Colorado Desert Depression; (3) features of the Great Transverse Belt—mountains, ranges, valleys, highland plateaus and fault line lineaments which extend east and west across the

State and constitute a great physical barrier between Northern and Southern California. (4) On the Pacific side, to the north, a group of natural units which includes the Sierra Nevada, the Great Valley, and the Coast Ranges proper; (5) the Peninsula Ranges of Southern and Lower California, and their associated features which separate the Pacific Ocean from the gulf and Colorado Valley, (6) the Continental Shelf with its individual ridges and projecting islands, and its valley troughs..[1]

Each of these six great divisions more or less differs from the others, yet each is characterized by its alternations of ribbon-like highlands and lowland valley plains. There are great differences in the details of the several regions and most of them were made at different epochs of the later periods of geologic time. The physiography of each is intimately associated with a certain group of master faults.

THE CROSS TRENDS

We are accustomed to divide North America along longitudinal lines into a series of north-south extending belts like those of the Appalachian, Mid-Continent and Cordilleran Regions.

It may also be divided latitudinally or into east-west extending belts, or zones, as the old-fashioned geographers did, to which climatic terms like the Arctic, Temperate, Sub-Tropical and Tropical Zones were formerly given. This latter subdivision into east-west extending zones is accompanied by certain similarly-extending lines or lineaments. One of these is better known as the "glacial line," having marked the south

[1]The term "Continental Shelf" is a misnomer, but no appropriate substitute at present occurs to me.

end of the former ice sheets of the Glacial epochs (geologically the Quaternary Period, or "Age of Man") and crosses the northern part of the United States as an irregular line well shown in most of our geographies.

THE TRANSCONTINENTAL LINE OF CROSS STRUCTURES

Most geologists have been content to consider that California is divided, as stated, into the Pacific and desert sides by highland barriers, and that all the lineaments of its surfece have been considered to have the north-south parallelism. But this supposed symmetry is not persistent, for it is abruptly broken across by the occurrences of highlands, valleys, and master faults which trend in an east-west direction. These highlands and valleys constitute the Great Transverse Structural Belt, recently defined by the writer.[1]

This line approximately follows our southern boundary. It comprises a series of physiographic and structural features, not necessarily continuous, although related, which consist of master fault lines, elongated mountain folds, plateau scarps, synclinal valleys and marine cliffs, which succeed one another across the continent in an east-west direction (a little south of east) from the westernmost of our Channel Islands to the east end of the Virgin Islands of the West Indies. More especially it extends from the west tip of the Channel Islands of California into Arizona at the Colorado River.

Beyond the Colorado River its lineaments continue eastward across Arizona, New Mexico, and part of Texas as master fault lines near the south ends of

[1] In a paper read before the Cordilleran Section of the Geological Society of America, Los Angeles, 1926.

the Colorado Plateau, the Rio Grande Ranges and the Great Plains Regions, and still farther eastward as the great synclinal troughs of the Rio Grande Embayment and the Gulf of Mexico. Its last eastward recognizable appearance is as the great fault escarpment north of Porto Rico and the Virgin Islands.

This belt separates the southern parts of Texas, New Mexico, Arizona, and California and all of the Mexican border region on the south from the northern parts of the states named, and divides California into two entirely different worlds. In fact it is the boundary line between Neo-Tropical and Temperate North America.

The transcontinental Southern Pacific railway system from Los Angeles to Galveston practically follows the northern end of the sub-tropical region, while the nearly-parallel Santa Fe system follows the southern border of the different regions to the north.

The chief features of the Transverse Belt in California are its structural lines—gigantic, elongated, east-west extending master faults and some folds, the former of which are mostly omitted from Dr. Willis's consideration and from his earthquake map published by the Seismological Society. In general, this hitherto but little appreciated lineament plays a wide and fundamental part in dividing California as well as North America into its Northern and Southern parts. The failure to appreciate the existence of these features and the accompanying geographic conditions has been the cause of a great confusion of knowledge.

Further comments on the mountains, valleys and faults of this lineament in California are more fully described under the head of Southern California.

THE PACIFIC AND DESERT SIDES

Again let the State be divided into two great divisions, north-south extending and somewhat artificial, the Desert and the Pacific sides, each separated from the other for much, but not all, of their lengths by the crests and scarps of several master highlands, which latter, for convenience, will be arbitrarily included with the Pacific side. These highlands constitute most of the length of the divides between the drainage of the Pacific Ocean on the west and the desert regions on the east.

One who tries to follow this latter classification too literally will find difficulties and inconsistencies which cannot be easily explained without a knowledge of the Transverse Belt.

GREAT BASIN FEATURES

All of the desert portion of Eastern California north of the Transverse Belt is the western part of the Great Basin Province of the Cordilleran Region, a province which lies east of the east-facing, north-south-extending fault escarpment of the Sierra Nevada of California. The region is characterized by altenations of long and narrow, belt-like, north-south extending ranges and valleys, which largely accompany great faults or rifts of similar directions. These features suddenly end to the south in the little understood portion of Eastern California, along a fault zone which runs from near Randsburg southeast to the Colorado River near Blythe where it is crossed out and succeeded by the structures and relief features of the east-west and northwest-southeast systems of trends.

Here, in this little known desert region of the Desert side between the 34th and 35th parallels of north latitude and the north and south ends of the Mojave and Colorado Deserts respectively, is the meeting place of three of the most important geographic features of different ages and trends, as may now be seen for the first time by examining the beautiful topographic sheets of that region recently made by the Department of Power and Light of the City of Los Angeles.

It is not necessary for us to describe further this relatively well known Great Basin Province or its southwest end known as the Antelope Valley portion of the Mojave Desert, as this has been sufficienty done by H. R. Johnson and others.

THE COLORADO DEPRESSION

The Colorado Desert or Depression, except in climate, is quite different from the northern, or Great Basin Province. It consists of a north-south extending, near and below sea level, valley plain or trough, one thousand miles long by a hundred miles wide, which lies between and below the highlands of the Peninsula Ranges on the west and the west sides of Southern Arizona and Mexico on the east. The southern and greater part of this area is now beneath the waters of the Gulf of California, while its northern end, formerly an extension of the same, is the partially reclaimed and fertile Colorado Desert portion (Imperial Valley of Southern California and of northern Lower California.

As a whole, this depression follows a comparatively ancient, north-south-extending trough that may be a

SIERRA NEVADA SUMMIT
Showing weathering and glaciation (Auto Club)

fault rift which, in late Miocene time when the north-south trends prevailed, may have existed along the entire east side of California. This former continuity, however, if it once existed, has later been crossed by the east-west trending structure of the Transverse Belt, and the northwest-southeast extending rifts.

THE PACIFIC SIDE

The northwest portion of the state with its many beautiful natural aspects and the sites of the older American settlements of California lies to the west of the Great Basin Province and to the north of the Transverse Belt. To some of its honored native sons this portion alone is California. Its history is one of romance and memories of pioneer days. Here, until lately, have been situated all of its great institutions of learning and its concentrated wealth. We stepsons of the south are partakers by tolerance of its halo of poetic tradition. To its inhabitants our entirely-different, southern region has been a back country, which even its scientists but grudgingly admit is a naturally different province.

This northern subdivision of the State presents striking alternations of north-south extending physiographic units, consisting of extensive highlands and valley plains. These include such well known features as the Sierra Nevada Highland, the great Valley and the Coast Ranges. All of these features end to the southward at the north side of the Transverse Belt which is popularly known by that vaguely defined, but somewhat appropriate term of "the Tehachapi," although it is not all embraced within the area of the mountains of that name. In fact, it includes a drain-

age divide created between the valleys of the north and the south by features of the Transverse Belt; thus including the Santa Ynez Range, the Topa-topa Range, the indefinite district which we herein call the Piru divide or wilderness, and the Tehachapi Range above mentioned.

THE COAST RANGES

The highlands of the western half of the Northern California Region between the Great Valley and the Ocean are the "Coast Ranges." They end to the south along the northern side of the divide of the Santa Ynez and Piru Creek drainage basins of the Transverse Belt. This change is probably controlled by the Santa Ynez fault line but in a manner too complicated to be here described. We have tried to show on our outline map the physiographic features of Southern California. (See Plate 1.)

The Coast Range highlands consist of a number of long and narrow parallel ranges—the Temblor, Diablo, Santa Lucia and San Rafael, separated by equally long and narrow valleys, such as the Carrizo, Cuyama, Salinas, Santa Maria, etc.

These are the beautiful ranges which give individuality to all the coastward side of Northern California, and which adorn the environment of San Francisco and other of its cities. They are largely composed of the Franciscan rocks and the white, diatomaceous, Monterey shales and brown, yellow and drab sandstones and clay shales of Cretaceous and Tertiary periods. A glance at their physical characteristics suggests that they are a stage or more older than the ranges along the coast of Southern California. Dr. J. P. Smith of Leland Stanford, the dean of California paleogeogra-

phers, states that the Middle Miocene was probably the time of the initiation of these mountains—a time when the outlines of the land were more extensive than now, and when the great Mid-Miocene epoch of volcanism was most active.

The present day aspects of the Coast Range Highlands, however, are due to many other later events of geologic history extending into the present time, which have been admirably set forth in a recent paper by Mr. Robin Willis,[1] a son of Dr. Bailey Willis.

According to Robin Willis, quoting Mendenhall,[2] "the Coast Ranges vary widely as to age." He (Robin Willis) also states that the structure is of an unusual type. It is controlled by the movements on the great faults of the region, folding being secondary—a condition which the writer has long alleged to exist in Southern California, and which he is glad to see so ably set forth by this author. "Many of the ranges are simple fault blocks but folding also has its influence on the broader features," which "are controlled by differential uplift due to deformation, as opposed to uniform uplift where the topography is controlled by differential erosion". In later pages we have endeavored to say this, perhaps, in less technical language.[1]

It has been the habit to carry this name "Coast Ranges" southward into Southern California, but this constitutes a grave error which has largely prevented a proper understanding of the latter region, for no

[1]Bull. Geological Society of America, Dec., 1925.

[2]These allusions to the work of Mr. Robin Willis have been inserted after the main body of this work was in type, and hence the omission of references to them on later pages. Our only points of difference are that he includes our "Transvere Ranges" in his "Coast Range" Group. This difference is of no importance at present.

continuation of, or analogies with this true Coast system of Northern California are to be found here, unless, as we shall show is probable, they are represented by the sunken Catalina ranges of the submerged Continental Shelf. One of the first essentials to the understanding of the geology of Southern California is to rid the mind of the erroneous concept that the Coast Ranges are found south of "the Tehachapi."

SOUTHERN CALIFORNIA

What is the enchantment that draws one to Southern California again and again? How may one describe or explain its individuality? Few, if any, have ever stopped to analyze its make-up or to seek the key to its attractiveness.

Does one come here to escape the chilly winters of New England, the fogs of Britannia, the smoke of the soft-coal districts of St. Louis and Pennsylvania, the mosquitoes of New Jersey, the mugginess of Boston and Washington, the malaria of the southern swamps, the twisters and tornadoes of the mid-continent area, the monotonousness of the prairies and the blizzards of the northwest? It is the charm of the Southern California climate and scenery—due to its varied geological and physical conditions—that brings you here, rather than the evils which drove you away from your former moorings.

Why is it that one never tires of its wonderful outdoors, its roads, its sea-borders, its picturesque valleys, its mountain canyons, its high-forested plateaux, or what the newcomer, not yet educated to its charms, may call its "desert wastes"?

The answer is found in the physiographic and geo-

logic conditions of the region which I am trying to describe in this paper in a manner not hitherto done. Southern California owes the uniqueness of its physiography to the great fault scarps and lineaments with which the fundamentals of its landscapes have been outlined. It is to the same processes which made these fault lines that we are indebted for the slight earth tremors which occasionally introduce themselves to our attention.

The term Southern California will be used to include all that portion of the State south of the north line of the Transverse Belt, including the last mentioned subdivision in it. This embraces practically all that portion of the State south of north latitude 34 degrees, 30 minutes, which corresponds with the great Santa Ynez fault line, the south side of Antelope Valley, the north side of the San Bernardino Plateau, the Dale Desert, etc.

SOUTHERN CALIFORNIA IS DIFFERENT

Southern California differs from Northern California, from which it is separated by a highland wilderness. It has its own type of highlands, valleys, islands, coast lines, rivers, deserts and other physiographic features. It is not only different but unique.

Southern California's natural relationships are not with her own state but with that vast region of subtropical America which within itself includes a score of wonderlands, deserts, cordilleras, plateaux, volcanic piles, peninsulas, islands, gulfs, straits—a vast tropical empire which barely peeps into the United States and of which Southern California is but the northwest corner. Capital she is indeed, of this neo-tropical realm

whose most remote provinces have recently and suddenly been opened to her by canal, motor roads, railways, steamship lines, and airplanes, tying her still more closely to the border states of the Southwest and to the outer provinces of Mexico, Central America, Panama, the Antilles, the Orient and Hawaii.

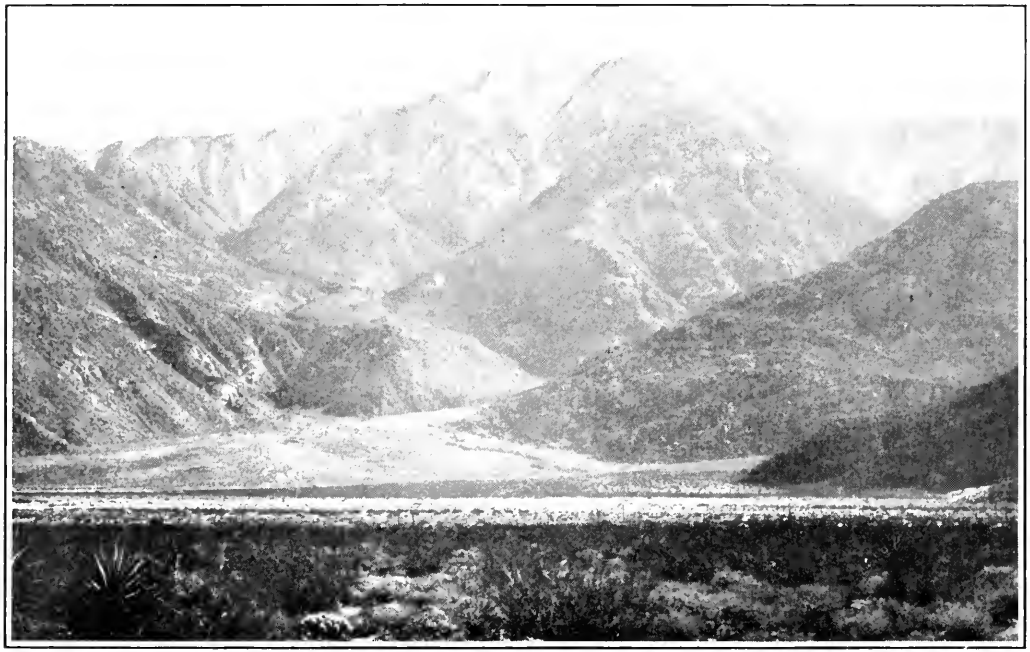
GEOGRAPHIC UNITS OF SOUTHERN CALIFORNIA

I cannot here give detailed descriptions of the many geographic units of Southern California, each of which could make the subject of a paper in itself, but must limit myself to a broad and sweeping picture of them. In no portion of the world of similar area are there so many geographic identities as here. Instead of the few physiographic units of majestic proportions as in Northern California, or the far-reaching units of plains, prairies and forest-belts of the eastern portions of our continent, the units are many, are of great variety and are encountered at short intervals. The accompanying sketch is an attempt by the writer to show on a very small scale the names and locations of the units of Southern California. (See Plate 1.)

THE HIGHLANDS

There are many kinds of highlands in Southern California which occur either in groups or as individuals. These vary in size from relatively small, single ranges of the San Pedro Hill and the Verdugo Range types, to gigantic features like the Peninsula Ranges, which extend a thousand miles from Riverside to Cape San Lucas in Lower California.

Some of these, the minor highlands, are elongated, folded ranges of sedimentary strata, such as the Ven-



EAST SCARP OF THE SAN JACINTO HIGHLANDS

tura Ranges and the ranges of the Piru Divide. Others, the master highlands, are extensive, high-standing fault blocks with plateau-like summits, and which consist mostly of granitic and metamorphic rocks of deep-seated origin. These blocks may represent the severed and pushed-up parts of former, near-sea-level plains (peneplains). The largest, highest and most extensive of these master highlands in Southern California are the San Gabriel, San Bernardino and San Jacinto Highlands.

These highlands have been little studied, classified or described. Even today no suitable map of them as a whole exists, except the small one herewith attempted. (Plate 1.) And yet some of them, like the ones mentioned, are physiographic units of such striking individuality that, could they be set aside from their interesting environments, each would prove a natural feature of greatest interest.

In this paper I can give only an impressionistic view. First I shall discuss them as consisting of two major groups—not systems—which will be called the Transverse and Peninsula Groups respectively. Besides these groups there are several relatively smaller individual features which stand alone, such as the San Pedro Hill, some other isolated hills along the borders of the sea, and the island groups which project above the submerged, coastal shelf.

Some of these highlands are simple domes or folds of sedimentary strata such as the Dominguez and Ventura Ranges; others are tilted fault blocks of previously-folded sedimentary strata such as the Santa Monica and Puente Ranges; while still others are master highland blocks of granitic and metamorphic rocks

from which former coverings of sedimentary strata have been removed by erosion, and which are bordered on one or more sides by steep master fault scarps, as in the instances of the San Gabriel and the San Bernardino Highlands.

HIGHLANDS OF THE TRANSVERSE BELT

The highlands of the Transverse Belt are many in number. They include: (1) All of the east-west islands of the Anacapa or Channel Group, the Santa Monica Range, the Santa Ynez Range, the various ranges of the Piru Divide and of the Ventura Group, the latter of which are mostly folds of sedimentary rocks which do not rise above five thousand feet; (2) Master Highlands of the San Gabriel and San Bernardino type, and certain minor ranges like the Verdugo, little San Rafael, Washington, Repetto, Montebello and Puente Hills, those latter being mostly low eminences made in Pleistocene time; and (3) certain large but little known ranges of the desert side, the chief of which are the Little San Bernardino, the Pinto, the Eagle, Bullion, Sheep Hole and Orocopia Mountains. These are much weathered fault blocks of various metamorphic granitic and effusive rocks, probably with some inclusions of Paleozoic sedimentaries.

THE PIRU DIVIDE

The term Piru Divide is herein provisionally used for an unclassified and complicated region which constitutes a highland barrier between the western portions of Southern and Northern California and is also the drainage divide between the Great Valley and the Santa Clara River Valley of the South. It is a union or meeting ground of most of the physiographic and

structural features of Northern and Southern California, including the Tehachapi, San Rafael, Santa Ynez, Topa-topa, and San Gabriel Ranges. Besides these, there are several large, unconnected highlands, such as the Fraser, Alamos and Pine Mountains. Several of the great master faults, the Santa Ynez, San Andreas, Tehachapi (Garlock) and perhaps others meet here and cross, or join one another. The western end of this district is dominated partially by the east-west trends and structures adjusted to what may be a continuous line of the east-west Santa Ynez and Bouquet Canyon faults, which separates the southern ends of the Coast Range features on the north from those of the northwest extending belts to the south.

THE SANTA YNEZ RANGE

This long, narrow, east-west-extending range parallels and overlooks the coast of Ventura and Santa Barbara counties, and is crossed by the State Highway through Gaviota Pass. It is practically an elongated fold of Cretaceous and Tertiary strata, and it is bordered on its north side by one of the Santa Ynez faults—one of the master rifts of California, which is closely followed by the valley of the Santa Clara River for an indefinite distance eastward to the San Andreas Rift southwest of Lancaster. Gaviota Peak is the highest summit—the peak which was first asserted to have moved northward twenty-four feet in thirty years, and later four and one-half feet southeastward.

THE VENTURA RANGES

Of the many geographic and geologic phenomena of Southern California the flexured Ventura Ranges in western Los Angeles and Ventura Counties are

among the most peculiar and interesting. These are a conspicuous assemblage of narrow, elongated, parallel ranges varying from two to five miles in width, which alternate with the valleys of somewhat similar dimensions. Among the features included in this group, the following may be mentioned: Sulphur, Hopper, Santa Paula, Oak Ridge, Santa Susanna, Simi and the ranges north of Camarilla and Calleguas Hills.

These individual mountains occur end to end in several parallel chain-like groups which, at least between the longitudes of Newhall Pass and the town of Ventura, extend in east-west directions. This belt of ranges is apparently enclosed between the two more rectilinear trends of the Santa Ynez and Santa Monica Ranges on the north and the south respectively.

While the belt as a whole extends in an east-west direction its individual ranges are bent, as if by horizontal shifting, into a broad arch with its apex to the north. This curvature is also indicated by the course of the Santa Clara River through the region, as it follows a synclinal valley.

The contours of these ranges and their horizontal arching in my opinion largely reflect the geologic structures of two different epochs of movement.

The individual ranges and valleys, mostly structural, consist of narrow-beaded, anticlinal and synclinal folds respectively. Erosion has been more active in sculpturing these structural folds than in the instance of the Dominguez Range, but both are alike in that the physiography broadly conforms to the structure. It is my present hypothesis that this narrow folding took place in an earlier epoch than the arching, and that originally it had a northwest-southeast direction.

The arching of the group of folded ranges, I believe, was the result of horizontal pressures exerted in east-west directions. It represents a portion of a great bend or partial buckle whereby the normal northwest trends were deflected more to the west. These aspects are discussed more fully in the chapters on structure.

The dual structural history is also largely reflected by the drainage. Several large streamways occur in the region, among which may be mentioned the Santa Clara River of the south, Piru and Castaic Creeks. Some of these, like the latter, are the antecedent streams of earlier epochs and cross the ranges at right angles. Others, like the Santa Clara, are consequent streams of a later epoch and flow in synclinal troughs.

The exposed materials of the Ventura Ranges are nearly all sedimentary rocks of Cretaceous, Tertiary and Quaternary ages. The latter predominate at the surface, as has been shown in the excellent earlier descriptions and maps by Eldridge and Arnold, and later by W. S. Kew.[1]

THE SANTA MONICA-ANACAPA CHAIN

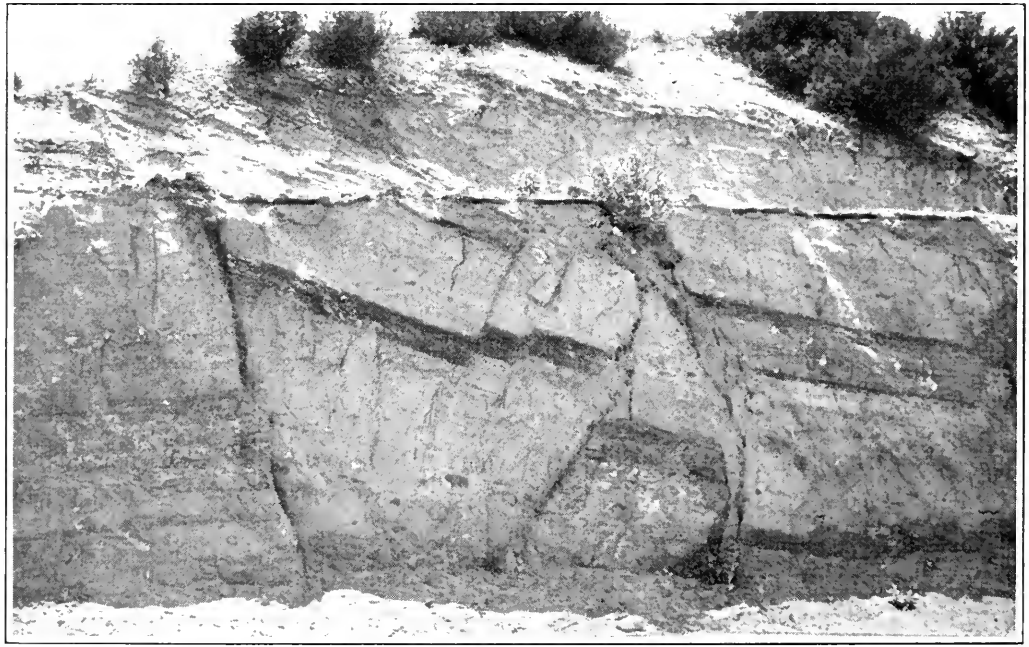
A ribbon-like range extends from Glendale westward for one hundred and thirty miles to the west end of the Channel Islands, which I will term the Anacapa - Santa Monica Range. Physiographically speaking this is a long and narrow east-west mountain range, the southernmost of the Transverse Belt. It is partially drowned by the sea and dissected into several individual summits of which San Miguel, Santa Rosa, Santa Cruz and the Anacapa Islands are

[1]Bulletins Nos. 309 and 753 respectively of the U. S. Geologrcal Survey.

members. The eastern half, from Point Moruga eastward, comprises the Santa Monica Range proper.

The rock materials are the familiar Cretaceous and Tertiary sediments, with the granitics and metamorphics of the basement complex sometimes exposed beneath them, especially along the south fault scarp line near Los Angeles. Toward the west end of the Santa Monicas there are unusually fine displays of the lavas, tuffs and dike material of the great mid-Miocene volcanism, when the plutonic forces last seemed active in this part of Southern California. Beautiful exposures of these rocks may be seen in Los Angeles in the cuts of Mulholland Drive as it leaves the Cahuenga Pass Boulevard.

It is impossible in this short paper fully to describe the beautiful configuration and interesting structure of these ranges. In general it may be said that they are both bounded on the south by steeper escarpments than on the north, and that this escarpment constitutes one of the great master fault lines of Southern California (See details in chapter on "Structure"). To its escarpment we owe all the beautiful "foothill" scenery of the Santa Monica and Hollywood districts. It is not easy to correlate the configuration of these ranges to their structure, but the fault line above mentioned is the master key to all the other features of the range which, in fact, is but a long and narrow, tilted, ribbon-like block on the northern or uplift side of the fault. Many other structural trends, principally of northwest-southeast extending folds, may be found in this narrow, ribbon-like range as in Griffith Park, but some were there before the mountain was made by the uplift, as above described.



SMALL FAULTS, GRIFFITH PARK, LOS ANGELES

THE MASTER HIGHLANDS OF THE TRANSVERSE BELT

In this paper we are using the term Master Highlands for those larger and higher mountain units of California which stand conspicuously above their surroundings. These are mostly composed of granite and metamorphic rocks of the Basement Complex, from which vast thicknesses of previous coverings of sedimentary rocks must have been eroded. In this category we place the Sierra Nevada Cuesta and its southwest extension, the Tehachapi Plateau, the San Gabriel and San Bernardino Highlands of the Transverse Belt, and the San Jacinto, Cuyamaca and other highlands of the Peninsular Plateau and, in fact, all of the last mentioned features.

These Master Highlands are not structural folds, but are apparently great, horst-like, upthrust blocks, the summits of which, as particularly exemplified by the San Bernardino Highland, are remnants of a former lowland peneplain which has been checkerboarded by fault lines, and the segments thereof later uplifted or depressed to various heights into the master highlands or the valley plains. Of course there are many other details, but we are not dissecting them with a scalpel.

Of the above mentioned, the San Gabriel and San Bernardino Master Highlands are the most conspicuous members of the Transverse Belt. Each consists of an elongated, summit-area of one or more great polygonal fault blocks which have been floated upward from ten to fifty thousands of feet between fault line borders. This estimate includes the thickness of sedi-

mentary rocks which once covered the originally deep-seated granitic rocks and which were denuded as the blocks uprose.

Many details of these highlands are to be mapped —sufficient to entertain microgeologists for years to come. We regret that space does not permit the insertion here of the more lengthy descriptions of these great features which I have in manuscript.

TRANSVERSE HIGHLANDS OF THE DESERT SIDE

It is only within the past three months that I have had maps of the Desert Side whereby its physiography and structure may in a degree be interpreted. By their aid I have been enabled to incorporate the greatly reduced outlines of the mountains on Plate 1. There are physiographic complexities on the Desert Side which we do not as yet venture to interpret. These are produced by the meeting and, at times, crossing, of the Great Basin, Transverse Belt, and Northwest-Southeast trends in that region. The East-West fault lines of the Transverse Belt continue through the region with undiminished displacement, however, as is more fully discussed in the chapter on structure. Some of the highlands, like the Little San Bernardino and the Pinto, are undoubtedly fault block uplifts along the East-West structure.[1]

[1]Note: The presence and abnormal character of the features of the Transverse Belt were first recognized by W. P. Blake, some seventy-five years ago (See Pacific Railway Reports for Route along the 35th Parallel, Vol. 5, Pl. 3, Washington, 1856).

His descriptions of some of the geographic and geologic features of Southern California are fundamental and classical. The significance of this most important structure was but faintly recognized, if at all, by succeeding geologists. Later studies by the writer, however, convince him that Professor Blake gave us an insight into a feature of fundamental and far reaching importance to the understanding of the paleogeography and geology of California. One reason for this omission has been the absence of adequate topographic maps east of the longitude of the San Gorgonio Pass. These now (1927) have happily been supplied.

VALLEYS OF THE TRANSVERSE BELT

The lowland valleys of Southern California are of many kinds and, owing to the plain-like character of the bottoms of the larger of these, we term them the valley plains. Some of these, like the Colorado and Mojave Deserts, are of very large magnitude. The details of these are well known and cannot be particularized here. Others of less magnitude are herein described as the Foothill Valleys and the Downey Plain. Besides these there are several proportionately narrow, smaller and elongated, ribbon-like valleys which occur along or between the great fault lines and which are trough-like and sometimes of the graben type. Of this latter type are the valleys of LaCanada, the Elsinore, Elizabeth Lake and similar valleys along the San Andreas Rift, the east belt of the larger San Jacinto Valley and parts of the passes known as the Tejon, Cajon and San Gorgonio. Likewise the Chuckwalla, Pinto and Amboy Valleys of the Desert Side are apparently of this graben type, but this is not certain.

The Santa Clara River occupies a long and narrow synclinal valley. There are various other kinds of small valleys, some of them in the highland areas called "potreros"; notably the San Jacinto and Morongo Indian Reservation Potreros in the foothills on either side of San Gorgonio Pass and many others, particularly those of the Peninsula Ranges. The two instances first mentioned occur at the intersections of fault lines.

There are also downcutting stream-course valleys, particularly in the mountain areas, but these are either absent, shallow, or otherwise inconspicuous in the

Valley Plains. I cannot give further space to the smaller valleys, but merely a few words concerning some larger valley plains.

THE FOOTHILL VALLEYS

The Foothill Valleys are the larger, fertile plains of the Pacific side of Southern California, in which most of the population lives and where agriculture is at its best. They are the lowland parts of the Transverse Belt and extend east and west along the south sides of the Ventura Ranges and the San Gabriel Highlands, and lie between them and the north end of the Peninsula Ranges.

Commencing at the west, south of the Santa Barbara Coast, lies the great submerged valley of the Santa Barbara Channel; next, to the east, are the elongated valleys between the flexured Ventura Ranges; then the three great quadrangular Foothill Valleys, San Fernando, San Gabriel and Ontario[1] respectively. These collectively extend eastward to the San Bernardino Plateau. Next east is the valley of San Gorgonio Pass, with its rich redlands of the Yucaipa and Beaumont Plains. Farther eastward still, out on the desert side, are extensive valley plains and basins of the Dale, Pinto and Amboy types.

The Foothills Valleys are primarily structural troughs. They are in parts and places synclinal, in others combinations of synclinal and faulted structure, and, in still other instances downfallen or depressed, trough-like blocks between faults. Some have

[1]The term Ontario Valley is herein used for the large quadrangular valley plain which lies between the north end of the Santa Ana Range on the west and the San Bernardino Highlands on the east. It is sometimes called the San Bernardino Valley, but the latter name is more appropriate for that subdivision of the larger features which lie to the east of the west bank of Lytle Creek.

been more or less thickly veneered by outwash of continental materials derived from the adjacent highlands (principally those to the north side), which has been spread over them by distributary drainages and in places they have been extensively buried in loess-like, wind-blown sand, notably near Guasti and Wineville.

VALLEYS OF THE DESERT SIDE

An east-west extending chain of Valley Plains also occurs on the Desert side of the Transverse Belt. The Amboy, Rabbit Springs, Dale, Bristol, Newberry, Twenty-nine Palms, Pinto Basin and the Chuckwalla Valleys are examples. Little or nothing has been recorded concerning these most interesting areas. They are primarily structural features from which vast quantities of material have been removed by the wind, and whose surfaces are veneered with various sized outwash rock materials from the adjacent highlands.

THE PENINSULAR HIGHLANDS

The Peninsular Highlands include all the ranges and valleys of the diversified, plateau divide between the main body of the Pacific Ocean and the Gulf of California. They extend for a thousand miles southward and southeastward from the Transverse Belt as they constitute the highlands of the southern portion of our state and of the peninsula of Lower California. The summit area is itself a varied region and consists of many subordinate ranges and valleys like those of San Jacinto, Santa Ana, Cuyamaca, Volcan and others of the smaller northern part which lies in Southern California, besides many others in Lower California. The plateau also has many circular or elongated pot-

reros and valleys, some of which are of considerable extent.

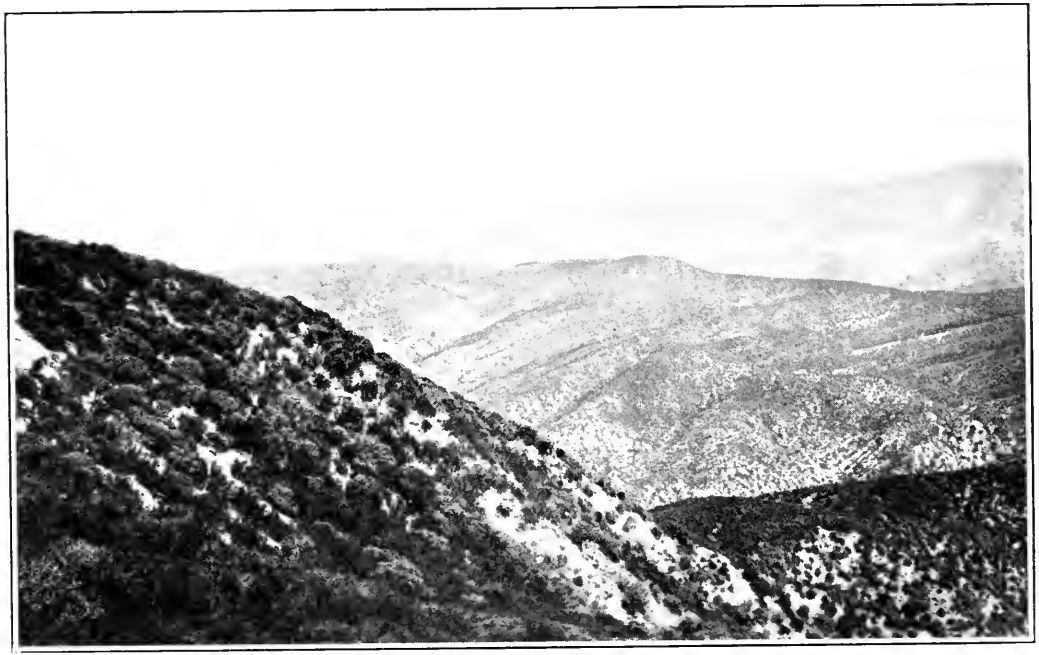
The feature, as a whole, represents a segment of a once more extensive land-surface which has survived from Eocene time[1] and which has since been cut into parts by diagonal faulting. Its east side shows suggestions of north-south faults which in the future may probably be proved to be related to those of the Basin Region. Its summit is diagonally crossed and striped by fault scarps and valleys, the lineaments of which suggest relationships to the later-made northwest systems, in so far as can be deduced from the little knowledge we have concerning them.

The east border of the highlands overlooks the great Colorado Depression and its outline is composed of irregular escarpments and indented by narrow valleys which cut into its outline on that side. Its western portion descends by stair-like benches and terraces towards the sea, ending at its borders in wide benches and picturesque cliffs and is attended in places by short, island-like, parallel ranges. The latter are not the Coast Ranges of Northern California, but distinctly fault hills, each a physiographic unit within itself, such as the San Pedro, San Joaquin, San Onofre, and Point Loma Hills.

VARIOUS FEATURES OF THE NORTHERN END

The Peninsula Ranges terminate to the north along an east-west cross section through San Gorgonio Pass, via Redlands, Colton, the north side of the Jurupa Mountains (north of Riverside) and the Santa Ana Pass of the Santa Ana River. In a general way the

[1]Hanna, Marcus A. Geology of the La Jolla Quadrangle. Geological Bulletin of the University of California. Vol. 16, No. 7, Berkeley, 1926.



OLDER PARALLEL RIFTS, SOUTH OF SIERRA PELONNA

path of the last mentioned stream between Redlands and its mouth approximately follows this line. This border also corresponds more or less with the south boundary of the Ontario Valley Plain.

There are many wonderful physiographic features associated with this northern end of the Highlands, which in places has been badly indented by erosion so that it is marked by many isolated, outlying hills of the Rubideaux, Riverside, Colton and Jurupa type.

These features include the San Jacinto Mountains and the Badlands Range, the San Jacinto Valley Graben, the Lakewood Horsts, the Grapevine and Reche Canyon Mountain Blocks, the Gavilan Country, the Elsinore Graben, the Santa Ana Range and the Downey Plain. That portion of the area between the San Jacinto Mountain and the Elsinore Graben Valley has been termed the Perris Peneplain by Mendenhall, and is supposed to be a remnant of the same, ancient, land-surface as that which is now also represented in the summit of the San Bernardino Plateau.

The San Jacinto Range is one of the three master Highlands of Southern California, and presents a more or less precipitous slope on the Desert side of 11,000 feet above the bottom of the Salton Sea at its foot. It is bordered on three sides by master faults, so that it is included in a long triangle with its narrowest angle to the south. The faults on its northern side were probably made in pre-Pliocene time, while the one on the east was probably initiated in the Miocene and greatly rejuvenated in the Pleistocene, as attested by the uplift of the marine Hathaway formation on its west side of the fault, to a height of 3000 feet above its former position at or below sea level. The San

Jacinto fault which borders the west side is probably of Pleistocene age.

The northern end of the Peninsula Plateau is characterized by the many northwest-southeast-extending master faults which cross it diagonally. The more conspicuous of these faults in turn block out many ranges and valleys of considerable magnitude. Among the mountains are the San Jacinto, Badlands, Lakewood, Santa Ana, Dominguez, and San Joaquin Ranges. The valleys include the Beaumont Plain, and the San Jacinto, Perris and Elsinore Valleys and the Downey Valley Plain.

THE DOMINGUEZ RANGE

The Dominguez Range is Southern California's newest, most valuable, and most interesting mountain feature. It consists of a line of low, domical hills which arise on a more or less continuous fold and which extend northwestward and southeastward like a beaded necklace from Balboa to the Santa Monica Range. Bordering the nearby Pacific Ocean for much of its course it constitutes a topographic divide between it and the Downey Plain. The range includes such hills as Bolsa Chica, Alamitos, Signal, Dominguez, Athens, Inglewood and some others north of Culver City. The range is so new that its surface contours still largely conform to the structure of the underlying folds. We have data for very definitely placing the age of this range as that of the latter half of the Pleistocene Epoch.[1] The fold is attended largely on its seaward side by the Inglewood fault, herein previously de-

[1]The writer has in hand a large unfinished manuscript on the Pleistocene and Recent Geology of the Los Angeles City Region which deals with the subject and the age of the La Brea and Ballona fossil remains.

scribed. Beneath the domes of this range almost priceless pools of oil have been found in recent years which have added vastly to the wealth of Southern California. The other ranges alluded to are well known and space forbids their further mention here.

THE DOWNEY VALLEY PLAIN

I use the name of Downey Valley Plain for the longest and largest of the Southern California valley plains. It borders the west side of the north end of the Peninsular Highland, and is a structural accompaniment of the last mentioned feature. The Downey Plain is often miscalled "the Coastal Plain of Southern California" and sometimes the "Los Angeles Basin." It extends southeast from the south side of the Santa Monica Range near Sherman in western Los Angeles for sixty miles to near San Juan Capistrano. It is bordered on its seaward side by the Dominguez and San Juan Ranges and on its north and northeast sides by the east end of the Santa Monica Range, the Elysian Park, Repetto and Montebello Hills and the Puente and Santa Ana Ranges. In size it is comparable to the largest of the Foothill Valleys and is the site of many flourishing farms and towns, including Los Angeles in part, Huntington Park, Fullerton, Anaheim, Santa Ana and other cities. The Ciegna, La Brea and Sherman Flats in south and west Los Angeles are the northwest extensions of this plain.

The valley floor is somewhat synclinal in structure with subordinate folds and the strong Puente Fault zone along its northeast side. Its substructure to depths of 4000 feet or more is strata of Pliocene and Pleistocene ages. Its surface is largely covered by

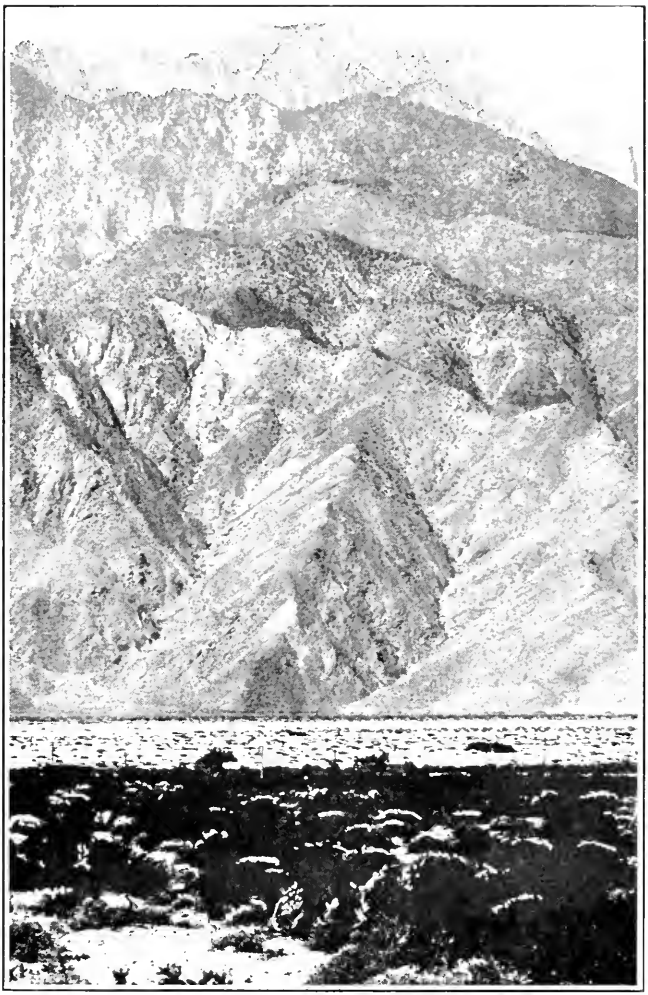
late Pleistocene and recent outwash materials from the north which have been deposited by the many present and former distributaries of the Los Angeles, San Gabriel and Santa Ana Rivers, which still empty into and widely spread their sediments over parts of it.[1]

THE DRAINAGE

Should a map of Southern California be made which would show the paths which the drainage might follow, it would constitute a bizarre pattern with many peculiar deflections, cut-offs and captures quite different in details from those which would be shown upon a map of other regions, such as the Atlantic Coastal Plain of the United States for instance, where the drainage flows in parallel and orderly lines down a normal coastward slope. The eccentricities of the drainage pattern of the Southern California region are largely due to adjustment to the structure by the stream courses or to the cutting-off and dismemberment of the former stream paths by later faulting and foldings. In some instances the fault blocks have risen directly across the antecedent paths of the streams, in others the streams have swerved around the ends of the rising blocks as they adjusted their courses to them. Short, consequent streams also accompany and conform to the steep slopes of the fault scarps and are sometimes disjointed along horizontally sliding fault lines.

Sometimes great talus fans are formed where the up-stream side of the country has been uplifted along a fault line. The Coastal ends of the streams show

[1]The reader who desires more detailed information concerning this interesting valley plain, is referred to the excellent papers by W. C. Mendenhall and W. A. English, published respectively as Water Supply Paper 139 and Bulletin No. 768 of the United States Geological Survey.



THREE FAULT BLOCK RIDGES, SAN JACINTO HIGHLAND
Erosion grooves in foreground

evidence of former extensions and retractions with the advancing and retreating shore lines and some of them are "drowned" or re-filled estuaries. The courses of the older streams as they cross the valleys are almost buried beneath their own debris, while the upper ends are in V-shaped canyons cut deeply into the edges and surfaces of the rising mountain blocks.

SUBMERGED CALIFORNIA

This is a wonderful and but little appreciated portion of the State, which borders the Pacific Coast at distances of from twenty to one hundred miles.

That portion opposite Northern California, which lies north of the Channel Islands archipelago (north latitude 34°) as far, at least, as north latitude 39°, is a comparatively smooth plain somewhat like that of the true Continental Shelf of the Atlantic side. Its uniformity is not broken by angular relief or relief of any kind, except a few evidences of cross grooves representing the former locations of now drowned valleys.

The Southern portion is a belt of submerged land, with its projecting mountain ranges, submerged valleys and drowned rivers, which have been made known to us by the so-called Sonic Depth Map of the United States Naval Department. Only the highest tips of the mountains are now visible above the surface as islands.

It is characterized by long, narrow ridges, in alternation with deep troughs. These submarine highlands and valleys, like those of the land, are arranged in, at least, two groups of different ages and directions. (See Plate 1.)

THE ABYSSAL ESCARPMENT AND COAST BENCH

The outer, or seaward, edge of the submerged continental margin is bordered by a very steep escarpment of nearly 10,000 feet, which suddenly leads down to the greater ocean depths. Whether this is a fault line or not is a debatable question. Some may theorize that it is the great master fault line of the California coastal region, but no one knows.

The coast lines of the mainland and the islands are bordered by a bench with a maximum depth of one hundred fathoms, which drops off suddenly to greater depths. I term this the Coast Bench for convenience.

The courses of many former land-flowing streams, now submerged, may be traced across the Coast Bench and the Continental Shelf. Some of these are direct continuations of stream courses which still exist upon the land. Others, like the one off Redondo, cannot be connected with any present day stream.

One of these stream valleys, which leads seaward from Monterey Bay is a deep valley of unusual proportions and rivals the great submerged Hudson Valley of the Atlantic side in size and depth. It is traceable seaward by the contours for a distance of over 80 miles.

THE SUBMERGED MOUNTAIN RANGES

The various islands off the coast of Southern California are the projecting tips to several interesting submerged mountain ranges, which I will briefly mention under the names of the Catalina and the Anacapa groups.

THE CATALINA GROUP

The Catalina Group consists of four northwest-southeast ranges, separated from one another by deep, valley-like troughs. Santa Catalina projects as a tip of land from the easternmost of these; San Clemente is the second one to the west; Santa Barbara forms the third one; while the fourth one closely parallels the top of the Abyssal Escarpment, but nowhere comes to the surface.

The ridges from which the Catalina group of islands rise, and the valleys which lie between them extend in west of north directions in harmony with the general direction of the San Diego Coast and the strike of the first group of northwesterly faults. They have all the aspects of true mountain ranges and inter-mountain valleys which were perhaps at one time above sea level. The trends of these ridges and valleys are also those of the Coast Ranges of Northern California. They extend a little to the west of the latter when projected upon the map.

THE ANACAPA RANGE

The Anacapa Range consists of the east-west line of islands which extends due west from the west end of the Santa Monica Range, of which they are a former geographic extension.

The Anacapa Group (also sometimes called the Santa Rosa Island Group in this paper) are popularily known as the Channel Islands. These rise to the north of a great submarine fault scarp of east-west directions, and are an integral part of the mountains of the Transverse Structural Belt, already described. They

show a diversified land topography and undoubtedly were once continuous with the mainland.

SUBMARINE VALLEYS AND FAULT SCARPS

Three, great, submerged valleys alternate with the ranges of the Catalina Group and are about of equal extent and area to them. There are also several precipitous submarine escarpments suggestive of fault lines, notably those in northwest directions along the east and west sides of the San Clemente and Catalina Islands respectively, and a long one in east and west directions which apparently attends the entire south side of the Catalina Islands.

Another conspicuous submarine escarpment, from 2500 to 3000 feet high, borders the south side of the Anacapa Range, and is continued to the south by the south-front fault escarpment of the Santa Monica Mountains.

TWO AGES OF SUBMARINE RANGES

The apparent presence in the configuration of two prevalent trends to the northwest and east-west respectively, together with certain facts of the geologic nature which cannot be here presented, suggest to us that two mountain-making epochs of California are represented in this configuration. These are: first, those of an older Northwest, or Coast Range System, and second, those of the East-West, or Transverse Belt. Northwest faultings of still later age have probably crossed both of these systems. There is still much to be learned.

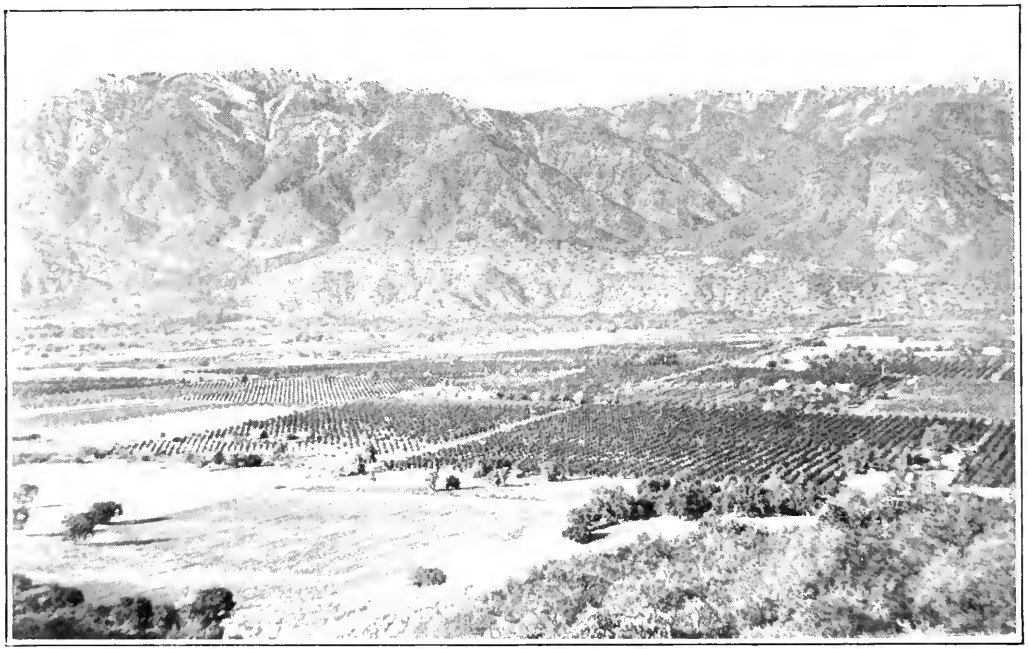
The Catalina Group may have been the former southern extension of the west side of the older or

Coast Range Group of Northern California, and I cannot but believe that it represents a former continuation of that system which has been depressed beneath the surface of the sea.

Likewise, the great east-west-extending features of the Santa Barbara channel, the Channel Islands and the great Anacapa Fault, represent vestiges of a former east-westerly-extending mountain system of a later age than the Coast Ranges.

It is suggested that the Santa Barbara Channel, which lies to the north of the Channel Islands, is a sunken valley plain of the type of the existing ones on the mainland. If this be true, then it is probable that both systems of mountains have participated in a later regional subsidence. The Shelf, as a whole, with its structural ranges, old river valleys and transecting stream valleys, has the aspects of a former land area that has been submerged.

If the events thus suggested should be proved to be true, what mighty vistas of geologic history and events in Pleistocene times do they open to the imagination. We dare not speculate upon them now.



SAN BERNARDINO MASTER FAULT SCARP
East of Redlands (Mendenhall)

PART FOUR

THE SCIENTIFIC BACKGROUND
THE STRUCTURE.

The geologic structure—especially the faulting—has been of tremendous importance in creating, outlining and defining the physiographic features of the country in its relations to climate, to distribution of water below and above ground, to the soils, to the occurrence of oil fields, to seismicity and to human environment in general. Without a knowledge of the occurrence and extent of the great master folds and faults of Southern California no one can have an understanding of the fundamental conditions that answer and explain the question "Why is Southern California?"[1]

Aside from the materials which enter into the making of a house, the ultimate aspects of the building will depend upon how these materials are arranged or put together to make the completed edifice.

The arrangement of the materials in the building of the earth, as well as of houses, is technically known as "structure." This includes the position and attitudes of the rock units relative to one another, such

[1]Prior to the recent successful utilization of geology in the matter of oil exploration, mere mention of the word produced an unfavorable mental reaction upon the average man, who associated it with things of but little human interest, such as vague pre-nebula hypotheses, dreary eons of Paleozoic time, dark, slimy seabottoms, with remains of millions of once creeping things, no longer living, with names as far from understandable English as possible,

as their tilting, bending, dislocation, faulting sequence, etc. Some oil geologists use the term "structure" merely for earth folds in which oil is found, but it is herein used in the broader sense.

The faulted types of structure are most evident in some physiographic features and the folded types in others; while in still other instances both types are associated. Folds sometimes pass into faults in their longitudinal continuations; in this vicinity they are unusually paralleled on one side by them. Likewise folds which are closely paralleled by faults sometimes lose their identity as folds and appear as fault blocks.

In Southern California the structure consists to some extent of arches (folds) of strata, which may bend either upward or downward (anticlines and synclines) but more conspicuously of long fractures or rifts,[1] called "faults", along the opposite sides of which the rock material has been displaced.

REGIONAL TYPES OF STRUCTURE

Variations in the types of structure and their details are visible in different regions of the world. In some portions the folded type of structure predominates, as is seen in the mountain regions of the Jura and the Alps, in the Appalachians and in the Rocky Mountains. In other regions, particularly the one in which we live, faulting appears to be a more dominant type of structure than folding.

Both sides of the great Pacific oceanic basin are bordered by lands where the fault-rift type of structure prevails, and which record subsidences of the floor

[1]The term rift is herein used in its ordinary dictionary meaning, to-wit, a rip, a crack, a tear, or a fissure. Such features are also usually fault lines, where the materials of one side of the rift have moved relative to those of the other.

of the basin as the bordering lands arose. This faulted type of structure began along the west coast of America in middle Tertiary time, succeeding the folded type of structure which accompanied the makings of the Rocky Mountains in early Tertiary and Cretaceous times.

REGIONS WHERE FAULTED TYPES PREVAIL

In some regions of the world, like the Dutch East Indies and the west side of the American hemisphere, the master faulting on a large scale prevails and constitutes important elements in outlining the general physiography. This is especially true of the Great Basin Province of Eastern California, Nevada and Utah; of the Trans-Pecos Provinces of Texas, New Mexico and Northern Mexico, and of California. In fact, at least one California geologist holds that the folding in this region is secondary to the faulting.

It is the prevalence of faults in this Southern California region which gives to it its marked physiographic individuality, the appreciation of which fact has been long delayed, owing to the dominance of Appalachian precedents in the minds of those who have attempted to interpret the fundamentals of its geology.

It is a great mistake to look upon the fault lines of Southern California with fear and forebodings as dreaded sources of danger. Better to view them as the causes of all the major conditions of our environment —the makers of our highlands and valleys, the great partition lines of the underground reservoirs which store our oil and waters—in fact the fundamental shapers of our surroundings to which the earthquake

movements are as trivial as are slight settlings of the ensemble of a majestic building.

THE STRUCTURE PROVINCES

The southwestern part of our country may be divided into certain, well-defined, natural provinces according to the directional types of structure which prevail in them.

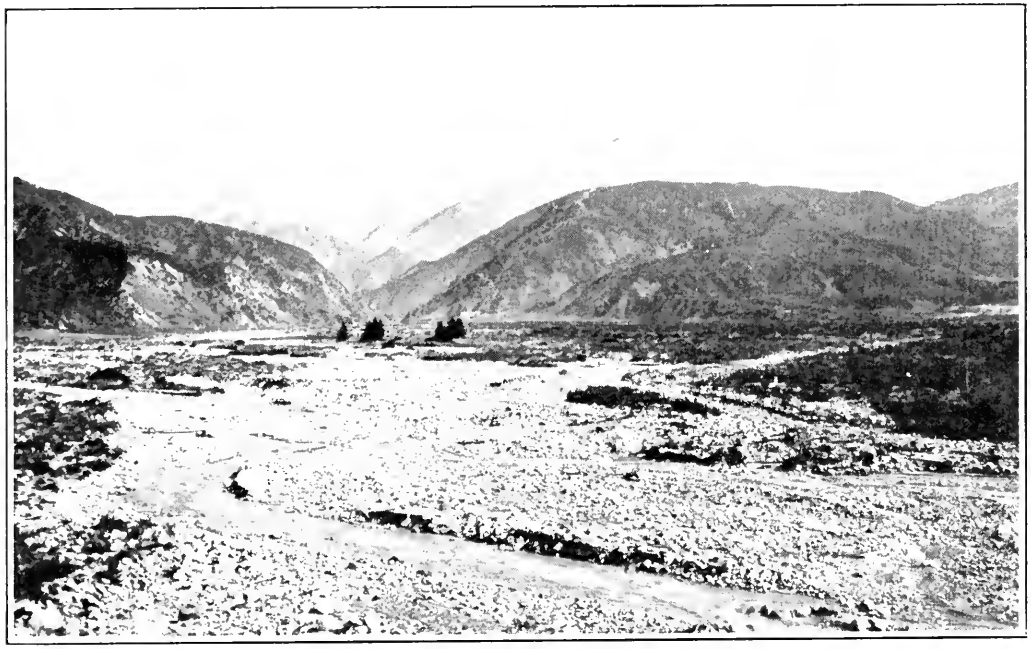
It is not desirable at this place or moment to give details of all these great structural provinces of the southwest, otherwise than those portions of them which lie within the state of California. Descriptions of the regions to the east are contained in a manuscript I have prepared upon the Trans-Pecos Region.

STRUCTURE PATTERN OF SOUTHERN CALIFORNIA

It is difficult to convey a word concept of the structure pattern of Southern California, although, as compared to some other regions, the structure is conspicuously reflected in the physiography. Much is beginning to be known about it, but more is still to be learned. Hence it must be understood that the following remarks, although based upon many years of individual observation, are only an endeavor to give an elementary concept of a very complex subject.

The highlands of Southern California may again be classified into two categories according to the simplicity or complexity of their geologic structures as reflected in their physiography.

The first of these is of the simple type, and usually consists of narrow, elongated folds or faulted blocks. The second type consists of irregularly shaped plateaux, usually more or less oblong and polygonal in out-



PARALLEL RIFTS OF SAN BERNARDINO SCARP
Cut across by Mill Creek (Mendenhall)

line such as San Gabriel and the San Bernardino Highlands. These may represent uplifted blocks of preexisting surfaces which themselves are composed of older and former structures. They are bordered by more than one of the master fault lines of different directional trends, and in their relief may be a record of more than one epoch of fault block displacement.

CONFORMATION OF THE PHYSIOGRAPHIC LINEAMENTS TO STRUCTURE

Most of the lineaments[1] of the Southern California physiography, including the direction of the folded ranges and the borders of the fault-blocked plateaux are coincident in occurrence with the direction of the great structural trends, folds, rifts and fault lines—which latter, in turn, may be classified by age and direction into several categories, as will be shown. In fact, the structure pattern of Southern California is largely a duplicate of the relief patterns as shown on Plate 1, so intimately are the two subjects related to one another, although there are some few exceptions to the general rule.

This relationship of structure to physiographic features in Southern California is due to the fact that the structural movements have taken place so lately in geologic time (Pleistocene Epoch) that a sufficient interval has not since lapsed for the destructive processes of erosion, such as sculpturing of the arched summits and rounding-off of the fault scarps, to efface the relationship between the two kinds of phenomena

[1]The term lineament is herein used to indicate conspicuous lines of the face of the landscape, such as ridges, valleys, fault scarps, etc., just as it is used in the dictionary sense for the conspicuous lines of the human countenance.

as has been done in regions where the folding and faulting are relatively older. Nevertheless, while the physiographic features of Southern California do thus reflect their structural origin, they also show variation in the degree of this relationship.

PREVIOUS STUDIES OF RIFTS

Some of the individual rifts of Southern California have been previously studied by geologists, including Fairbanks, Lawson, Noble, English, and others. For nearly twenty years I have been making a more or less close study of them in Southern California. A manuscript map of these was made by me fifteen years ago, but its publication has been delayed pending the constant accumulation of further data, and other obstacles not necessary to mention. This map shows material differences with the fault map later made by the Seismologic Society of California.

Excellent topographic maps and the relief model of the hitherto but little known desert side of Southern California made by the Colorado River Surveys of the Los Angeles City Bureau of Power and Light present the physiography in beautiful detail and show many rift lines hitherto undescribed. Likewise they furnish details for verifying previously formed concepts of the wonderful phenomena of the region mentioned which I had seen and studied in the field many years ago, and thus they enable me to present my previous conclusions with greater certainty and assurance.

FAULT STRUCTURES AND EARTHQUAKES

Most earthquakes, as I have noted earlier in this paper, are vibrations set up in the earth's crust as the result of slipping or movement along portions of fault

SUB-RECENT PARALLEL FAULTS
San Andreas Rift, near Pettiway

lines. These vibrations are often noticeable over great areas.

The movement along the fault line is not the ultimate cause of the earthquake, however. This is something deeper and less explicable. It is most probably some great mass-movement within the plastic sub-crust—a jarring, vertical settling or horizontal movement of a segment of the rocks of the outer zone of fracture, like that which takes place when one piece of floating ice is broken from another.

Owing to this relationship between the earthquakes and fault structures it becomes very necessary for one who wishes to understand the subject of earthquakes in relation to Southern California also to appreciate the origin, occurrence and history of its extensive systems of faulting.

FAULTING

The presence of faulting is indicated by the bold escarpments of mountain borders, trough-like valleys, and by benches, foothills, "kern buts," "kerncols," (gun-sight gaps) faceted spurs, (salients)[1] springs, ponds, "green spots" and other phenomena, as more fully set forth in the writings of Fairbanks, the California Earthquake Commission, Noble, Lawson and others. Master rifts may also be present beneath the areas of valley plains and yet unobservable at the surface, where they are usually concealed by the overlay of more recent formations. This latter fact is one which has an important bearing upon matters to be discussed later.

CLASSIFICATION OF THE FAULTS

Extensive dissertations on the kinds of faults—normal, reverse, horizontal, rotational—may be found in any text-book on geology. For the purposes of this paper the faults of Southern California, which are mostly normal with some conspicuous exceptions, may be first classified into two general categories according to their relative size, occurrence and geographic conspicuity. These may be termed the master and interior faults respectively, after the manner proposed by Professor Chester Longwell in discussing the faults of Southern Nevada.

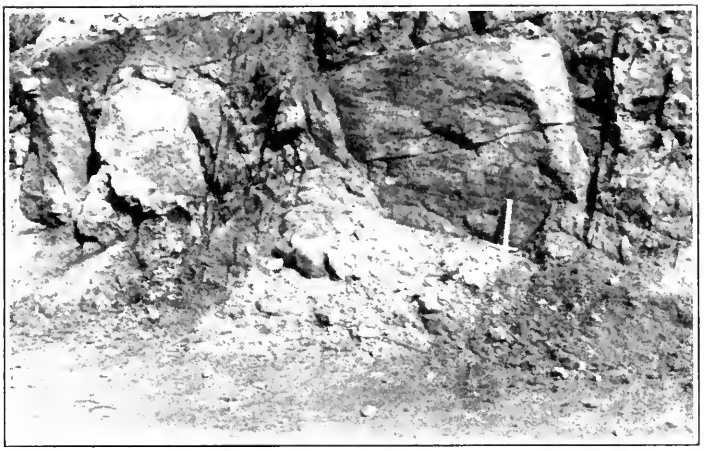
[1]Truncated salients (or "spurs" as they are called by Davis), which denote fault lines, attend the south border of the Verdugo Range west of Burbank and in the north part of Glendale, also the northeast side of the San Rafael Range, west of Devil's Gate, and many places along the south front of the San Gabriel and San Bernardino Highlands. They are superbly shown along the courses of the great rifts through San Gorgonio and Cajon Passes, especially along the north scarp of the San Jacinto Range near El Cabezon. The faces of the triangular facets of the truncated salients have themselves often been considerably modified by the later development of drainage grooves in them so that they now present the outline of an inverted Y. Conspicuous examples of these are seen northeast of Pasadena and near Eaton Wash. along the south side of Verdugo Hills and elsewhere. The relative antiquity of the fault lines may be predicted from the degree of erosion of their facets.

MASTER FAULTS

The master faults are faults of great displacement which persist throughout long distances and more or less coincide with the broad features of the topography. Master faults, like the great Balcones fault of Texas, the Grand Wash Cliffs of Arizona, the Wasatch fault of Utah and the Sierra Nevada faults of California, constitute conspicuous lineaments of the physiography and may outline geographic units of large size. They are often traceable throughout long distances from tens to hundreds of miles. In Southern California they are usually associated with one or more of the borders of the greater physiographic units and usually mark the boundary lines between the master highlands and the larger valley plains. They have vertical displacements of as much as 15,000 feet.

In this category of major faults we place, among others the Newberry, Cadiz, Pinto Mountain, San Andreas, Mill Creek, San Jacinto, Elsinore, Puente, Anacapa, Santa Ynez, Bouquet Canyon, San Gabriel, Sierra Madre, Santa Monica, Cucamonga and other fault lines, as indicated upon the accompanying map (Plate II). They are more fully described in other parts of this report.

These phenomena collectively constitute geologic and physiographic features of extraordinary and stupendous interest and are fundamentally and predominantly the chief factors in giving the present day individuality to the scenic aspects of Southern California. After the reader gets a first grasp, even in an elementary way, of their locations and extent, as herein presented upon the accompanying plate (Plate II), they will gradually grow in importance as he learns to recognize them in



FAULT LINES OF SEVERAL DIRECTIONS
Griffith Park Road, Summit Pass

nature. Adjectives fail to express their grandeur and significance. Even photography and sketching are insufficient to give adequate concepts of them.

INTERIOR FAULTS

There are also many faults that do not make the borders of the physiographic units and are not necessarily conspicuous in the topography. There usually occur in the interior areas of the physiographic units, and in general are far less observable than are the master faults. Sometimes the summit regions are subdivided into subordinate ranges and valleys by these secondary fault lines. This is notably true in the instances of parts of the summits of the San Gabriel, the San Bernardino and Peninsula Highlands and of the Perris Plain regions. In instances the lower highlands are striped into more or less rectilinear linea-

ments by these subordinate fault traces. This is notably true of the City, Washington, and Repetto Hills in Los Angeles. These subordinate fault lines usually extend in directions which are approximately opposite to those of the master rifts, and in instances may be complimental to them. Many of them have northeast-southwest directions. Some of them are older than the master faults, some are newer.

RECTILINEAR PLAN OF THE FAULTING

Most of the master fault lines are characterized by long continuity in comparatively straight lines (rectilinearity) although there are some exceptions to this rule.

Instances like the tangents of the San Andreas rift are traceable for two hundred miles or more in a single direction, with relatively slight deviation from a straight line. There are many other master faults of similar character, notably the Cadiz, Newberry, Mill Creek, San Jacinto, Elsinore, and San Gabriel faults.

Sometimes, though seldom, the general direction of these faults may be slightly jogged, offset or interrupted by minor cross faults. But their long-continued rectilinearities are conspicuous characteristics which are among the most marked features in the geology and physiography of Southern California.

There are also some few and exceptional instances of faults of curvilinear directions, as in the case of those which accompany the flexured Ventura Ranges.

NATURE OF THE FAULT LINES

The master faults are not necessarily single fault lines, but sometimes consist of several, closely-spaced faults which collectively constitute a narrow zone.

These are in places conspicuous along the courses of the San Andreas, San Gabriel and San Jacinto faults. Zones of this character may be seen along the south sides of the Verdugo and San Gabriel ranges.

A narrow, trough-like zone of faulting accompanies the San Andreas Rift along most of the north side of the San Gabriel Range, through the Cajon Pass and along the southwest base of the San Bernardino Highland.[1] San Francisco is situated on a narrow fault zone of this character which there accompanies the San Andreas rift (See Plate III). Its members are plainly reflected in the physiography of the city and surroundings. For the purposes of this paper the narrow zones may be considered an individual fault line. When a collection of parallel fault lines or zones occur at widely separated intervals throughout a broad area of country, they constitute a belt of faults which may be termed a belted group. There are several of these belts in Southern California. These will later be described.

EXTRA TERRITORIAL EXTENT OF THE MASTER FAULTS

The great master fault lines and structures which are manifested in Southern California are not confined to its territory but extend beyond its borders to the east and southward. The San Jacinto, Elsinore and other master fault lines can be traced into Mexico to the southeast just as can be some of the great master faults of Trans-Pecos Texas and New Mexico. Because

[1]The details of this portion of the rift along the north side of the San Gabriel Range have recently been published by Noble in the Carnegie Year Book No. 25, Washington, 1925-26, pp. 416-423. Much of the data of value concerning the Cajon Pass in an appendix to the U. S. Geological Survey Guide Book of the Santa Fe Railway Route, was placed under my name by the editor, who should have accredited it to Dr. Noble.

of the same lamentable lack of interest that has until recently allowed all of the desert southwest to remain terra incognita, we have no knowledge of details of these faults beyond the international line. Nevertheless, these continuations have bearings upon the earthquake question in Southern California, for it is emphatically and decidedly wrong to speak of them as having their southern termini here.

NATURE OF THE DISPLACEMENTS

The movement which takes place along a fault line results in what is called "displacement." These displacements often aggregate thousands of feet and have accumulated through vast periods of time.

The displacements along the master fault lines are largely in vertical directions, varying but slightly from the perpendicular, but there are conspicuous examples of gigantic displacements of other kinds, in which the movement was horizontal-drifting or over-thrusting (where one end of the faulted block is pushed over the other).

MOVEMENTS ALONG FAULT LINES

Movements along fault lines may be continuous through great lengths of time, and practically unobservable. It is improper to look upon the great fault scarps, often thousands of feet in height, as records of a series of earthquake disturbances, for the blocks may have moved upwards without a jar, just as slow movements of this kind may be observed along active lines of faulting in mines of today.

Movements along fault lines may also be sudden and intermittent in kind, and they may occur locally

rather than throughout long distances along the rift line.

The actual fault displacements, either in vertical, horizontal, diagonal or overthrust directions, may vary from a few inches to a few feet in amplitude.

When more or less vertical, the major rifts are supposed to be deep fractures or breaks in the outer zone (zone of fracture) of the earth's rock girdle, which lose their identity as they approach the zone of flowage. The depths of the fractures may extend to twenty miles or more—no one knows—until they are lost in the more plastic zone of flowage.

The amount of the nearly vertical displacements or a group of closely spaced displacements, may vary from a few inches, as may sometimes be seen in a fresh roadside excavation, to as much as 15,000 feet, as is evident in places along the north side of the San Gabriel Range; of over 10,000 feet along the east end of the south side of the same highlands; of over 10,000 feet between the summit of the San Bernardino Highland and the San Jacinto Valley near Eden Hot Springs; and of at least two miles on the east side of the San Jacinto Range, as may be seen at a glance by looking upward to the top of San Jacinto Peak from the flat of the Salton Sea.

Let not the casual reader be appalled by the totality of displacements or think that they represent single catastrophic movements. They were made by many small movements during long past epochs of geologic time. All the great, geologic events have required incomprehensible numbers of years for their accomplishment such as are hardly appreciable to the human mind. The aggregate of these great, scarp-producing

KERN RIVER RIFT LINE
Accompanied by "kernbuts" and "kerncols" (C. H. Lee)

movements have been no more sudden than have the many great invasions of the ocean waters back and forth across most of the area of our continent.

In instances of drifting the two sides of the fault displacements have been sliding past each other in horizontal directions instead of vertical, with stresses and strains like those encountered by placing the flat sides of two books tightly together, and dragging them in opposite directions with jerky movements equivalent to alternations of stresses and releases of strain.

Horizontal movements of this kind in California are supposed to have chiefly characterized the past history of the San Andreas rift. One of these movements is believed to have accompanied the San Francisco earthquake of 1906. Dislocation of the stream lines by such movements is indicated by Noble who says that in one place, three miles south of Cajon Pass, four ravines which come down from the San Bernardino Mountain slopes are displaced 150 feet to the northwest. Noble also suggests a horizontal displacement of twenty-four miles along the San Andreas fault. He does not consider this a positive conclusion, however.

Other suggestions of horizontal displacement along this rift, besides those given by Noble in the paper previously cited, are the dislocations in the stream patterns of the Santa Ana River and Mill Creek as they cross the rift zone on leaving the highland, and the apparent drag to the southward of the east ends of the supposed east-west rifts which mark the summit of the plateau itself. It has even been suggested that the entire southwest face of the San Bernardino plateau has been moved some twenty miles from a former po-

sition opposite the northeast end of the San Gabriel Plateau. If true, such a movement, of course, involved a vast length of time. Misconceptions concerning alleged movements of this kind in recent years have caused the confusion concerning earthquake prediction.

A great horizontal "buckle," complicated by thrust faulting, which apparently extends through the apex of the arched trends of the Ventura group of flexured ranges, may also be a result of regional, horizontal drifting.

A compressive thrust-fault of fair proportions has been pointed out by Kew[1] as existing along the north side of San Cayetano Mountain and the south side of a portion of Oak Ridge. Another of local character is cited by Noble on the north side of the San Gabriel Range, where the granite is pushed over the later sedimentaries of the desert border. Recently a great overthrust of some thirty miles has been reported from near Las Vegas, Nevada, by Hewitt and Longwell.[2]

RATE OF MOVEMENT

Various wild guesses have been made as to the present-day rate of movement along the San Andreas rift. It has even been estimated at as much as one and one-quarter miles in eighteen years. The Coast Survey studies previously mentioned estimated that Gaviota Peak had moved twenty-four feet northward in thirty years. To tell the truth, no quantitative estimates are as yet reliable.

At the present moment it appears that no observable

[1]U. S. Geol. Survey Bull., No. 753, p. 100, and map.
[2]Bull., Geological Society of America, 1927.

measurable movements have taken place in recent time. The Carnegie people at Pasadena are preparing a series of experiments to determine if such movements exist or are detectable.

TIME OF THE MOVEMENTS

Movements have been occurring along these fault lines during long periods of time, in some instances extending back to the close of the Eocene epoch of Tertiary time. Try to conceive how long it has taken to raise the great San Bernardino escarpment some 7,000 feet by little jog-like movements here and there, along its extent. It defies the grasp of the human mind, and yet this escarpment was made only yesterday in geologic time. The movements which have produced the superb physiography of Southern California have mostly taken place in prehistoric (Pleistocene) time, but there are still occasional after-effects which cause the mild tremors of the present. Some modern geologists, unfamiliar with the local geological history, infer that the present-day movement is as active as in times past, but in my opinion this is a mistaken hypothesis.

CROSS FAULTING

Definite knowledge exists in some instances that faults of one directional group have cut across those of another. Some of the master highlands are of a complex structure and their outlines have been blocked out by two or more fault lines of different ages and directions. This has resulted in the fault block or "paving stone" types of structure."

The writer has previously shown that this crossing of the structure trends of one age by those of another

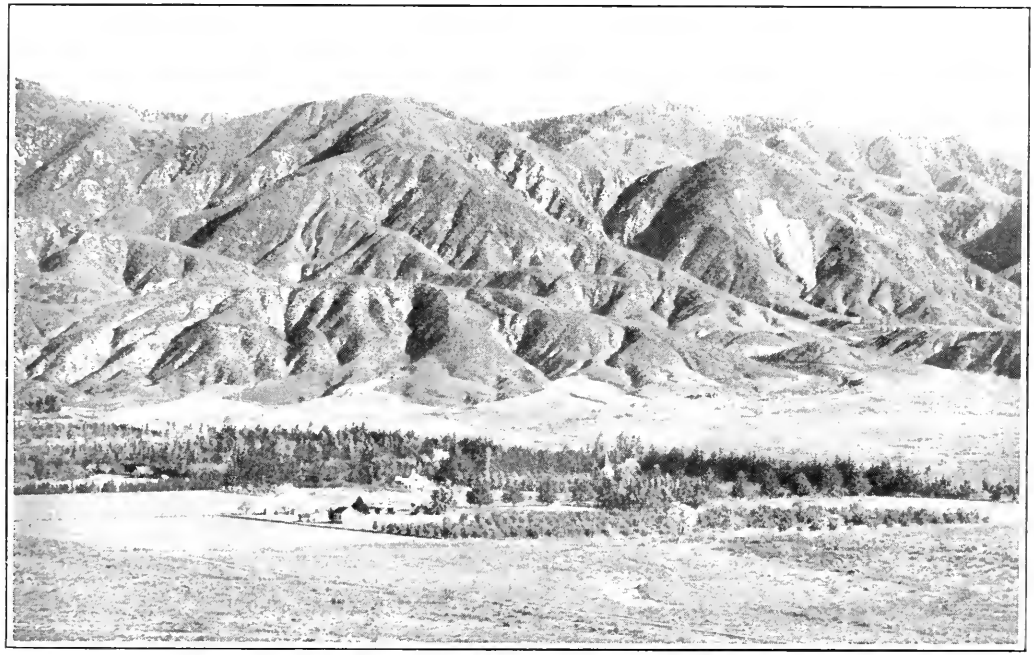
has taken place in various geologic periods in the Trans-Pecos region of Texas. The northeast, southwest trends of Appalachian relationships (Marathon ridges) are cut across by trends of north-south directions (Rio Grande ranges) probably of early Tertiary (Rocky Mountain) age. Both of these are again crossed by northwest trends of later Tertiary age and Pacific relationships.[1]

At Los Angeles, older, northwest folds in the east end of the Santa Monica Range are cut across by east-west faults, and the latter are cut across by faults of the Second Northwest system. Other instances of crossings of the trends in Southern California can be given. Nearly all of the larger mountain passes into Southern California represent gaps along places where there has been a meeting or a crossing of the trends.

The crossing of the fault lines of one system by those of another is notably observable on a large scale in the outlines of the San Gabriel, San Bernardino, San Jacinto and Peninsula Ranges. It is likewise observable in some of the other physiographic features like the Perris peneplain, the Puente and San Pedro Hills and the east end of the Santa Monica range, where in each instance master fault lines of one directional system and of an earlier date are cut across by master faults of another and later system. Noble has noted how the Basin Range type of faults are cut out by the Garlock fault.

The northern part of the north-south trending Peninsula Highland is crossed diagonally from a northwest to southeast direction by several master rifts of the

[1]See Physiographic Atlas of the U. S. Geological Survey No. 3 by the writer. Also see map by C. L. Baker which accompanies Bulletin 117 of the University of Texas Bureau of Technology.



SAN BERNARDINO SCARP AT ARROWHEAD
Rises six thousand feet. (W. C. Mendenhall)

later northwesterly system, including the San Jacinto and Elsinore rifts. It is likewise probably cut across and terminated at its north end by the east-west fault lines, which may continue eastward through San Gorgonio Pass into the Desert Side.

Furthermore, it seems apparent that the belts of parallel fault lines of one system, such as we have described in this paper, have been cut across by belts of another age and direction. On the Desert side it may be plainly seen that the older belt of Basin Range faults of north-south direction have been cut out by the great Garlock fault of northeast direction; that the latter, in turn, was cut out at Tejon Pass by the faults of northwest directions, which latter also cut out the east-west belts of faults of the Cucamonga and Pinto types at the Pacific and Desert sides.

In addition, it will be found that the process of the crossing of a belt of parallel, major faults of one particular epoch and direction by those of another belt of later age and direction has taken place upon a still grander scale throughout tropical and sub-tropical America, all the way from California into the northern edge of South America and to the eastern edge of the Caribbean.[1]

THE FAULT BLOCK STRUCTURE

In instances where a belt of faults of one direction is crossed by another of a different direction, the crustal block between them may rise or sink, this producing what is known as the fault block type of physiography, as in the instances of the San Gabriel,

[1]Taber, Stephen. "Great Fault Troughs of the Antilles," Journal of Geology, 1922.
See also: Hill, Robert T. Fundamental Geographic Relations of the Three Americas, National Geographic Magazine, 1896.

San Bernardino, San Jacinto, Morongo and Bullion Master Highlands. The physiographic units resulting from this type of structure may be broadly compared to those of the old-style, brick pavements that still prevail in some parts of the world, in which some of the blocks have been pushed up above the others and some have been lowered.[1] The fault blocks, with but few exceptions, are more oblong or belt-like than equal-sided. Consequently the resulting physiography, is in most instances, of the elongated belted type. The fault blocks have various attitudes and aspects. Some are upthrust, some are depressed, some are tilted, some folded, as has been described more in detail by others.

Not only do the highlands of Southern California consist in part of fault blocks of this type bounded by structural lines, but some of the valley plains also. These latter may be considered down-thrown blocks, partially of faulted origin, and usually bounded on at least one side by linear faults.

Several of the larger valleys like the Fernando and Downey plain are bordered on one side by strata dipping towards the center and on the other by fault displacements.

CUMULATIVE AND RENEWED UPLIFTS ALONG FAULT LINES

In instances, the highland and lowland blocks may be alternately rising and sinking. Again it is also probable, as shown by cross-sections of the Peninsula Highlands in San Diego County, that the general succession of faults, folds and fault blocks from the interior shoreward has resulted from a series of cumulative uplifts of the continental side away from the sea.

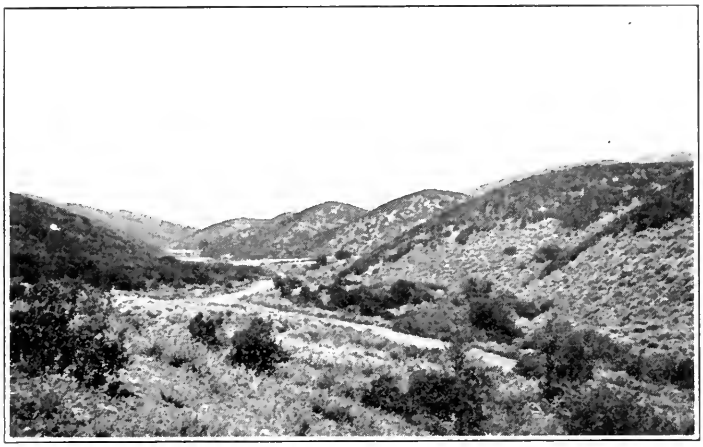
[1] R. T. Hill, Bull. Seismological Society of America, 1920.

Although the data are still somewhat indefinite, it may be stated that a portion of a generalized north-south cross-section of the Los Angeles Region conveys the suggestion that there has been a succession of fault and folding movements between the mountains and the sea in Pleistocene time, at least until the Dominguez Range is crossed. Beginning at the north with the block between San Gabriel and Sierra Madre fault, one encounters a succession of newer and lower ranges as he goes southward each of which has a steeper slope and a fault scarp on the seaward side. It also seems evident that with the initiation of a new range to the seaward the older blocks to the interiorward in this succession collectively received an additional upward impulse. There are complications in this cross-section as the results of the cutting out of older trends and folds by newer movements, which render this deduction still somewhat indefinite and tentative.

Movement is also often renewed in later geologic epochs along structural lines which were made in previous ones. Examples of this on a broad scale are frequent. One is the apparent fact that all of the faults and folds of the Transverse Belt correspond in position and trend to the site of a persistent, ancient seaway, or geosyncline, of Paleozic times (called the "Sonoric Depression" by Dr. Charles Schuchert).

THE BELTED GROUPS OF FAULTS

Studies and analyses of the structure patterns shows several wide zones of parellel faults, which extend across continental expanses in great, belt-like assemblages, any one of which may be several hundreds of miles in length and many miles in width. Furthermore it will be evident that some of these belted groups of



BEADED FAULT BLOCK BETWEEN PARALLEL RIFTS
BOUQUET CANYON

one age may have a characteristic orientation, often different from the trends of others of a different geologic age.

Structural phenomena of this type may be seen on a larger scale in the great mountain systems of North America, such as the Appalachian, Rocky Mountain and the Pacific Ranges. The western side of the continent, in particular clearly shows such a succession of belts of structures of various ages, each with its own individual direction. These are as clearly recorded on the face of nature as if marked on a blackboard with different colored crayons—the belts of one epoch in upright lines of white; of another epoch in left diagonals of green; of another in horizontal lines of red; and of still another direstion in lines of yellow, and so forth. In some instances, as in those of the Santa Monica and Puente belts, the elongated mountain blocks are not

composed of corresponding parellel folds, but are elongated, tilted monoclinical blocks each of which consists of a series of segments of cross folds of opposite directions which have been inherited from some preceding physiographic condition that has since been defaced by the later structures.

PROVISIONAL CLASSIFICATION OF THE RIFTS OF SOUTHERN CALIFORNIA

With full knowledge that our classification is ephemeral and incomplete, for conveniences of discussion, I am going to arbitrarily and tentatively classify the many fault rifts of Southern California into four directional belts or groups.

1. Rifts of north-south directions.
2. Rifts of northwesterly directions (first group).
3. Rifts of northeasterly directions.
4. Rifts of east-west directions.
5. Second group of rifts of northwest southeasterly directions.

The different groups of belted structures are in most instances of different ages. Although deductions are not final as to this, I will tentatively hold, for example, that the north-south extending ranges and valleys of the Great Basin and Colorado Depression regions are practically reflections of displacements of similar trend which were made at the beginning of, or before, the Miocene epoch as has been set forth by others; that some of the first, north-west group of true Coast Ranges of Northern California and probably the Catalina Ranges of the Continental Shelf developed in late middle or post-Miocene inasmuch as early Miocene strata are folded; that the Transverse trends were formed in Pliocene and early Pleistocene and the second group of

northwesterly trends in the middle and later Pleistocene epochs. The Garlock fault is apparently older than the San Andreas and newer than the Basin Range faults.

FURTHER DEFINITION OF THE BELTED GROUPS OF STRUCTURES

The belted zone of faulted structures may be further defined as follows:

1. The North-trending Group. This group in Southern California includes the great Gulf of California (Colorado) Depression, which follows the east side and trend of the Peninsular Highlands. The group is related to the Basin Range trend, which lies in line with it to the north, but which is separated from it by the "Transverse Belt."

2. The first or Coast Range Group of northwesterly faults. This is represented by the trends of the Coast Ranges of Northern California and the partially submerged Catalina trends of the Continental Shelf. Its direction is about north 40° west.

3. The Northeast-trending Faults. The Tehachapi (Garlock) fault is a conspicuous example of this group. Although not so conspicuous in the structure pattern of the region as are some of the other trends mentioned, other northeasterly trends significantly occur in several localities of Southern California, as will be further described.

4. The Transverse or East-west-trending Group. It consists of master faults and folds which accompany the Great Transverse Belt. In this category is included the anomalous group of curved faults and folds elsewhere described under the head of the Ventura Flexured Ranges.

5. The Second Group of Northwesterly Trends. This occurs in California in the wide territory between the Colorado River at Blythe and the Pacific Ocean at San Diego. It is also found in Southwest Arizona and adjacent Mexico. It is a large belt of master fault lines, about which more will be said later.

The order in which the belts are given is a tentative approximation of their age sequence, which will undoubtedly be modified and adjusted by researches in the future.

THE NORTH-SOUTH TRENDING BELTS OF FAULTING

Practically the whole of Eastern California north of the Transverse Belt consists of a series of north-south trending ranges and valleys, which owe their position and grosser outlines to a series of faults of similar direction. This is the western part of the Great Basin Region of California, Nevada and Utah. The Colorado Depression may have been synchronous with this group in time of origin, which was early, or pre-Miocene.

The Sierra Nevada Highland is bordered on the east side by a gigantic, northerly fault scarp, and it is practically a cuesta-like fault block, the summit of which slopes to the west-lying Great Valley. The fault trends slightly more to the north-westerly than the belt of north-south faults and rifts of the Great Basin Region.

The careful analyst of the topography in the field, as delineated upon the maps, will observe north-south, fault-scarp lineaments along the east front of the San Bernardino and San Jacinto highlands, along the course of Whitewater Creek at Palm Springs and

other localities. These, although not continuous with the main Sierra Nevada fault, are of similar direction and somewhat in line with it.

Collectively, the north-south structures are broadly reflected in both the Great Basin and in the Colorado Desert Regions of California, although the continuity between them is now interrupted by the later-made features of the Transverse Belt.

These analagous lineaments, north-south highlands and depressions on either side of the Transverse Belt may or may not represent vestiges of a once continuous, north-south structural-zone which was broken across by the later development of the east-west structures of the Transverse Belt and revived along the path of the Whitewater, Palm Springs and, perhaps, as yet undiscovered, faults of the San Bernardino and San Jacinto Mountains.

THE COLORADO DEPRESSION

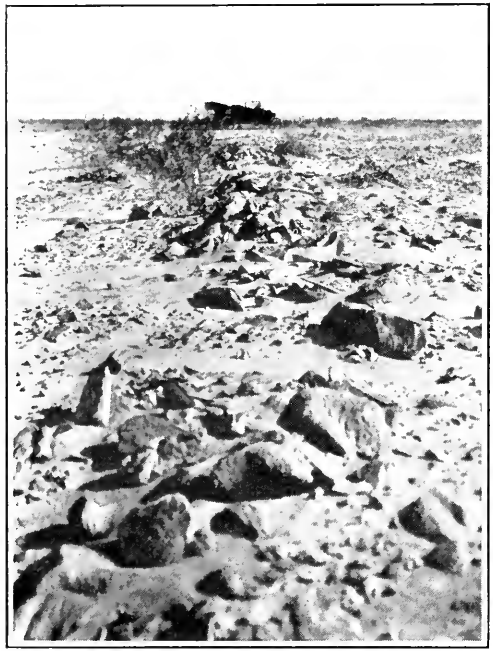
Although one cannot as yet produce much stratigraphic evidence of the fact, one cannot avoid the conclusion that the Colorado Depression, which is but the northern end in California of the Gulf of California, is a structural trough. This lies between the highlands of the Peninsular Ranges on the west and the Southern Arizona and Sonora regions on the east. Its northern end is abruptly terminated by a fault escarpment which accompanies the south side of the highlands of the Transverse and Northwest Belts. Abundant evidences are found of the uplift of the highlands along the fault lines to the north side of the depression, a notable instance being seen along the highway through the Mecca Hills between Mecca and

Shaffer's Well. The Pliocene marine sediments which are found below sea level to the south near Westmoreland and elsewhere, have been here extensively uplifted, faulted and folded.

While no conspicuously identifiable, single fault is visible on the west side of the depression, several north-south extending faults may be seen which are evidently vestiges of a great step-down zone. These lie in line with trends of both similar faults of the Whitewater type on the east side of the San Bernardino highlands and the great Sierra Nevada fault far to the north, facts which suggest that there may once have been a long line of such displacements along this general longitude.

The border between the west side of the desert depression and the east side of the Peninsula highland is made ragged and jagged by a number of long and narrow valleys between southeasterly trending divides of the highland, which extend towards and into the main body of the desert. These features are adapted to the extensions of major southeast rift lines which cross the highlands diagonally from the Pacific side.

The origin of these north-southerly extending rift lines along the west borders of the Great Basin and Colorado Desert Regions certainly antedates the late Miocene in age, although the movements may have begun in an earlier epoch and have been later revived. The aggregate displacement along this indefinite, west side, rift line, as seen in the east front of the San Jacinto Range, must in places exceed 11,000 feet. At least three thousand feet of this movement must have been accomplished in Pleistocene time, as is testified by the Westmoreland Pliocene sediments



RIFT LINE SHOWING DISTRUBANCE ON THE COLORADO DESERT FLOOR

PECULIAR VEGETATION FOLLOWING RIFT
Near Arrowhead Hotel

(Hathaway formation of Francis Vaughan), which have been uplifted to that extent on the west side of the north-south fault zone.

THE NORTHWESTERLY FAULT BELTS

Faults and rifts of this direction occur throughout a wide belt of the westerly half of North America, and largely south of the Transverse Belt on either side of the Mexican border, between the Santiago Range of the Trans-Pecos Texas Region on the east and the west margin of the continental shelf on the west. There are conspicuous instances of the northwesterly faults cutting out the north-south trends at El Paso, Texas, and other places.

There is some suggestion from the data which I now possess that there have been two or more epochs in Southern California when northwesterly structural trends prevailed, or, as may otherwise be stated, that the Basin Range epoch of dominant north-south trends was succeeded by an epoch of northwest trends; the latter, in turn, by an epoch of east-west structures, after which another epoch of the faulting in northwest directions may have occurred. This theory implies that one of the groups of northwest structures preceded the east-west Transverse structures, and that the other succeeded it. The possibility of such a sequence is suggested by the relations of the east-west faulting to older northwesterly folds which lie across the east end of the Santa Monica mountains in the City of Los Angeles and elsewhere and by the fact that the latter structures are in turn cut across by a later set of northwesterly faults of the Puente system.

In general, however, I wish to say that the divi-

sion of the Northwest trends into two groups is not entirely satisfactory to me, and that the classification used is probably more geographic than genetic. I have placed the northwesterly faults of the Coast Range and Submerged Continent Shelf in the older group and these of mainland Southern California in the later. In fact, many of the northwest fault lines shown on Plate III are of the later age.

FIRST GROUP OF NORTHWEST TRENDING STRUCTURES

It has been my opinion, based on the researches of others in this field, that the Coast Ranges of Northern California present two aspects of structure, one of which consists of more or less closely compacted folds and faults of a North 40° west trend, and the other of a later series of north-westerly faults which may have paralleled them or cut slightly diagonally across them. Others consider that both movements are of similar age. The first group of structures was supposedly produced by the Coast Range revolution of late Miocene or Pliocene age. The second group of movements was supposedly of Pleistocene age. The structure of the Coast Range is now being thoroughly described by Professor Clarke of the University of California in a paper to be presented soon. I defer any opinions of my own on this subject to his.

Conspicuous physiographic units occur in which the older north-west structures are apparently outlined by the master fault lines of later epoch. The San Rafael Highland Block of the Coast Ranges, for example, is bordered on either side by the Cuyama and Sisquoc master rifts which may be of the later northwest systems. It is not within my province or ability,

however, to authoritatively discuss the geology of Northern California.

NORTHWEST STRUCTURE OF THE CATALINA GROUP

While the Coast Range structure proper abruptly ends as a physiographic feature at the north side of the Transverse Belt, there is much reason to believe that its structrual affinities may be found to the southward in the northwest trending Catalina ridges and troughs of the submerged Continental Shelf.

Analyses of the submarine contours of the Continental Shelf show that the troughs and ranges there are divisible into two groups of opposite trends, which are probably coincident with ancient directions of folding or faulting. The first of these, of northwest direction, we have termed the Catalina group, and the second, of east-west direction, the Anacapa group.

The Catalina group of trends, so far as is indicated by the still imprefect maps of the submarine contours, consists of alternating ranges and valleys suggestively like those of the adjacent mainland.

The position and trends of the Catalina portion of the shelf, although situated slightly west of a southward projection of the Coast Ranges, strongly suggests a relationship between the two regions, the continuity of which has been broken by the development of the east-west structures of the Anacapa Island group and a later subsidence of the Catalina group.

STRUCTURE FEATURES OF THE GREAT TRANSVERSE BELT

No more interesting geologic features exist in in California than the faults and folds of the great

Transverse Belt which, as previously mentioned, extend in irregular sequence and sometimes in indefinte expression from the westernmost end of the Channel Islands eastward to and beyond the Colorado River into Arizona, where they are associated with the southward discontinuation of the Colorado Plateau. These features are reflected in the relief of both sea and land, and on both the Pacific and Desert sides. Among the highlands which are delineated in part by the east-west structures are the Santa Ynez, Santa Monica, San Gabriel, San Bernardino, Little San Bernardino, Eagle, Pinto and others, and more or less the Anacapa group of islands. The Santa Barbara Channel, the Foothill Valley, Rabbit Springs, Dole and Chuckwalla Valleys are some of the lowland features which accompany these Transverse structures.

THE ANACAPA LINEAMENT

The Transverse Belt is accompanied by many master fault rifts of great conspicuity, some of which are herein announced for the first time, while the existence of others has only been grudgingly admitted. One line of faults, which I will term the Anacapa Lineament, extends almost continuously across the state from the south end of San Miguel, the westernmost of the Channel Islands, to the Colorado River 500 miles east.

I consider this line to be one of the most conspicuous and important structural lineaments in all California. To its presence we owe many greater scenic features, such as the islands, the Santa Monica coast, the Beverly, Hollywood and Pasadena foothills, the great south-front of the San Gabriel Range, and remark-

able scarp lines of the desert side which heretofore have not been mentioned or described.

This lineament may be divided into three or four segments of approximately equal lengths which may be named as follows: (1) The Channel Islands segment; (2) the Santa Monica segment; (3) the Cucamonga segment, which follows the south side of the east half of the San Gabriel Range, and (4) the Pinto Mountain segment—a rift which follows a line past the north side of the Pinto Mountains from the vicinity of the Pipes, on the east side of the San Bernardino Plateau, to the Colorado River.

The lineament, although composed of several distinct members, practically constitutes a nearly continuous fault line of almost three hundred miles in length, the displacements of which aggregate from 5,000 to 15,000 feet. The westernmost member of the line, as is indicated by the closely-spaced contours of the Sonic Depth Finder Map of the United States Navy (See Plate I), follows the south side of the Channel Islands from their western end to the mainland. East of the islands it parallels the south side of the Santa Monica Mountains from Point Muga to near Santa Monica. From thence eastward to the east end of the Santa Monica Range its course makes the south fault scarp of these mountains as in the vicinity of Beverly Hills, Hollywood and East Hollywood. It practically follows that part of Los Feliz Boulevard between Western Avenue and the Los Angeles River. This latter portion of its course consists of several parallel faults.

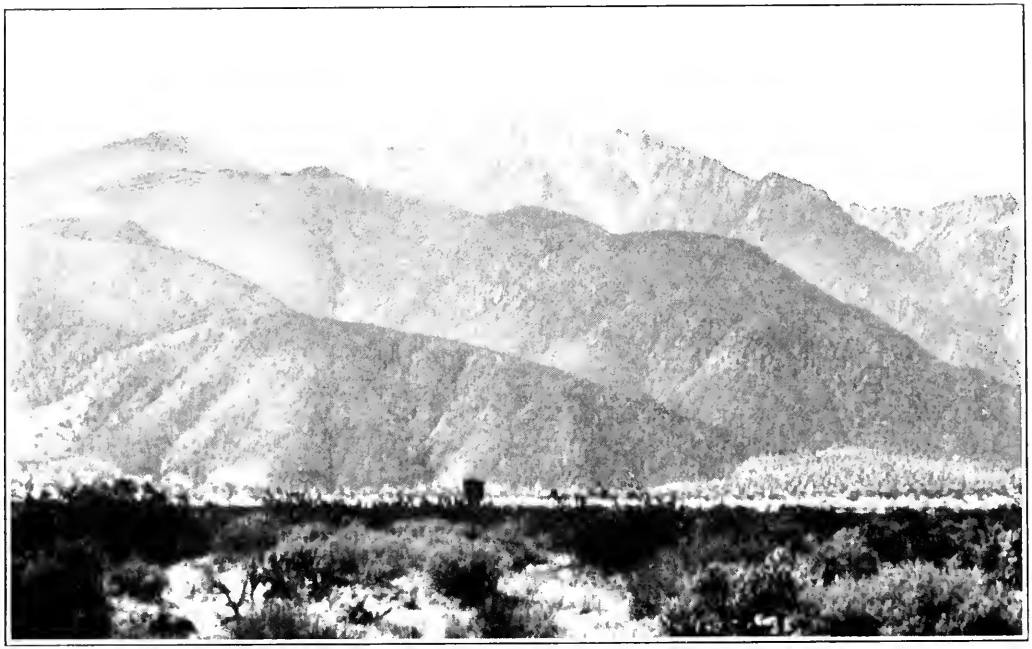
Details are lacking as to the course of the fault through Tropico, Glendale and Eagle Rock. More

probably the continuity has been interfered with by being crossed by later northwest faults passing approximately along the course of the Los Angeles River and through the northeast side of Griffith Park. It may also make an echelon jog to the north of Pasadena and from there continue eastward along the south foot of the San Gabriel Range, where the latter borders upon the San Gabriel and Ontario Foothill Valleys. This portion of its extent is indicated by the steep topography of the adjacent highlands. Its further direct course eastward is apparently discontinued by being crossed out by the San Andreas rift at Cajon Pass. If the fault crosses the San Bernardino highland, its path is not definitely known, although one which corresponds to it is shown on some of the fault maps. To the east of the San Bernardino Plateau the lineament continues to the Colorado River as the Pinto Mountain fault—a remarkable and conspicuous feature, not hitherto named or described.

OTHER FAULT LINES OF THE TRANSVERSE BELT

Several other great rift lines of the Transverse Belt are known. Some lie to the north of, and parallel to, the Anacapa master rift above indicated. Among these may be mentioned the Santa Ynez, the Santa Barbara and Bouquet Canyon faults. Of this group of faults the Santa Ynez is the most conspicuous, as its line is one along which there has been considerable activity of late, as at Santa Barbara and near Lompoc.

A few other faults parallel this line to the south. Among these are the Banning and Lawrence faults of the San Gorgonio pass and Riverside regions, the latter of which is herein noted and named for the first time.



BELTED RIDGES BETWEEN RIFT LINES, CAJON PASS

Likewise, there are at least three hitherto unmentioned east-west rifts of the desert side. It is the absence of many of these features from the Earthquake Map of California that is regretable.

THE SANTA YNEZ FAULTS

Some twenty-five miles to the north of the latitude of Los Angeles, the Anacapa fault is paralleled by one or more great east-west faults. One of these, as has been reported by others, borders the Santa Ynez Range on its north side adjacent to the Santa Maria country. Another may probably follow the south side of the range along the Santa Barbara-Ventura Coast.[1]

The western portion of the fault on the north side of the Santa Ynez Range is better known, but the eastern continuation is indefinite. It may parallel the north side of the Topa-Topa Range, and, in my opinion, it may ultimately be connected with the east-west rifts of the upper part of Bouquet Canyon, which are intercepted by the San Andreas Rift, or one of its parallels, a few miles southwest of Lancaster. If this southern line exists, as some seem to doubt, it may extend south of the Topa-Topa Range. Possibly it may even there bend to the southeast into continuation with the San Gabriel fault of Kew, or extend eastward into continuation with the Soledad fault.

[1]In instances, knowledge of some of these faults is deficient and sometimes details may be disputed. Such instances are of trivial importance, considering the large amount of known data, and in no manner negate the broader facts herein set forth. Even in California some of the biggest things are too big for some observers to see. It is the old story of not being able to see the woods for the trees.

THE EAST-WEST FAULTS OF SAN GORGONIO PASS

At least two very conspicuous, east-west master faults pass through San Gorgonio Pass. These, in conjunction with the San Andreas Rift, have been strongly influential, not only in producing the physiography of that gateway to Southern California, but also the conditions which attend the northern termination of the Peninsular Highlands.

A portion of the course of the northernmost of these faults, which may be termed the Banning fault, has been partially described by Francis Vaughan.[1]

This passes through the southern portion of the foothill mesas north of Banning and Beaumont. During the summer of 1927 the writer, assisted by Mr. John C. Hazzard, traced this fault farther westward through Hog Mountain and concluded that its course probably continued westward through Crystal Springs Pass, three miles east of Redlands. Its still farther western continuations, now largely buried beneath late formations, may probably pass north of the outlying hills of the Jurupa type, which occompany the north termination of the Peninsula highlands, and the south side of the Ontario Valley, near Riverside and Colton. If so, this explains much concerning the abrupt northward determination of the Peninsula highland in this region.

The definite continuation of this fault eastward from the San Gorgonio Pass is lost beneath the sands of the Coachella arm of the Colorado Desert, but there is a suggestion in the topography that either it or the Lawrence fault, or both, may be represented in

[1]Geology of the San Bernardino Mountains, University of California Press.

that direction by the Orocopia Lineament which passes by the north end of the Chuckwalla Mountains, and which is described on a succeeding page.

THE LAWRENCE FAULT[1]

Besides the east-west extending Banning fault, on the north side of the San Gorgonio pass, another and parallel one was also observed by me on the south side of the pass and named the Lawrence Fault. This parallels the south side of the pass just south of Banning and Beaumont and the north border of the San Jacinto Mountains. It passes through the north side of the Potrero de San Jacinto and enters the San Gorgonio pass proper south of Cabezon Station, near which its course is marked by truncated facets. Its course south of Banning makes a rectilinear fault valley, which is easily identified on the United States Geological Survey Map of the San Jacinto quadrangle, and by springs and kernbuts which attend its course through Lawrence's ranch, the locality from which it has derived its name. The fault has not been traced across the Badlands Range, and the presumption is that it is an older feature.

An associated fault line parallels the Lawrence fault on the north within a mile's distance, and between it and the valley of the pass at Banning. Knowledge of the presence of the Banning and Beaumont east-west faults through the San Gorgonio Pass explain the trough-like nature of that great feature. The Banning and Lawrence faults are probably of pre-Pliocene origin, although later movements have occurred along them, and indicate that the pass existed as remotely as that time, at least.

[1]First mention.

INTERIOR EAST-WEST FAULTS OF THE MASTER HIGHLANDS

Several subordinate ridges and valleys of the summit region of the San Bernardino Highlands extend in east-west directions, as will be seen on the topographic maps. These may be the vestiges of ancient folds and faults of similar directions, which prevailed in the ancient peneplain, of which the summit region represents a remnant, before it was dismembered into segments and certain of its blocks elevated into the present master highlands.

There are also several suggestions of the east-west rifts in the San Gabriel Range, for some of its peaks survive along east-west lines, while many of the valleys have similar directions and are followed by the heads of the San Gabriel, Bouquet and other canyons. The great east-west Cucamonga fault which makes the south border of the east half of this highland has been previously mentioned as a portion of the Anacapa lineament.

Minor evidences of the east-west structure system are seen in the trends of some smaller features, such as the Eagle Rock Valley and the Raymond Hill fold south of Pasadena, the First Street anticline and Sunset Boulevard faults in Los Angeles, and probably the axial directions of the San Jose and Montebello hills.

SUGGESTED EAST-WEST RIFTS OF THE DESERT SIDE

The newly made topographic sheets of the Desert Side contribute many new and unsuspected data. They enable us to show some hitherto unrecorded lineaments in the physiography, which confirm some of the deduc-

SAN ANTONIO PEAK
Fault block structure of the San Gabriel Highland (Putnam)

tions made from hard field-work in that region. These maps clearly show the meeting places of the north-south, the northwest, and the east-west belts of of structures. In fact, the district covered is a meeting-place of all the great belts of structures mentioned.

Three conspicuous, parallel, east-west lineaments are here included in a belt about thirty-five miles wide. They extend eastward from the vicinity of the San Bernardino mountains and San Gorgonio pass to the Colorado River between the towns of Needles and Blythe. Their courses are marked by strong rectilinear escarpments, the mountain and valley borders, and other features characteristic of fault line topoggraphy in California. They may be successively mentioned from north to south as the Pinto Mountain, the Eagle Mountain and the Orocopia Mountain lines respectively. Each of these apparently has a displacement to the north, but the studies I have made are as yet too insufficient to present details.

THE PINTO MOUNTAIN RIFT

The course of the Anacapa Rift is resumed east of the San Bernardino plateau by a great, rectilinear, east-west lineament which I term the Pinto Mountain Fault. This is first seen in the vicinity of the locality on the map of the San Bernardino quadrangle designated as "The Pipes", and continues east, in an almost straight line to the Colorado, past the south side of the Dale Desert, the north side of the Morongo (Little San Bernardino) and Pinto Mountains and through the lately-mapped Dale Desert on into Arizona about twenty-eight miles north of Blythe. This is one of the three longest and most conspicuous fault lineaments of California. There is some evidence

that this fault-trend continues indefinitely south of east across Arizona below the southern edge of the Colorado Plateau into New Mexico. But little more than the mere fact that it exists can now be definitely stated regarding it.

THE EAGLE MOUNTAIN LINEAMENT

Another line of east-west faulting of the Desert Side, as indicated in the topography, lies about fifteen miles south of and parallel to the Pinto Mountain fault, and corresponds to the rectilinear north side of the Eagle Mountains. It passes through the Pinto Basin and the middle of the Little San Bernardino Highland. Its westward continuation, if it could be traced, would pass by the northwest end of the Indio Hills and to a connection with the east end of either the Lawrence or Banning faults of San Gorgonio Pass.

THE OROCOPIA LINEAMENT

Probably a third rectilinear east-west rift of the Desert Side of the Transverse Belt might be called the Orocopia Lineament. It may be indicated by a nearly-straight line ninety miles long, drawn between Coachella on the west and Blythe on the east. Actual fault contacts, such as would cheer the heart of those geologists who demand more than physiographic testimony[1], may be seen in the Mecca Hills on the road from Mecca to Blythe. From thence the eastward extent of the rift is strongly suggested by escarpments

[1]A proper appreciation of the great master fault lines of Southern California has been long delayed owing to the oppositions of a school of geologists who oppose the direct testimony of the physiography as expressed in nature and upon good topographic maps and as has been long alleged by the writer, "Any one," remarked an opponent, "can take a topographic map of Southern California and draw lines along the boundaries of its major units and call them faults." He little realized that his words spoken in unfriendly criticism, expressed the great truth which I have endeavored to inculcate for years, and which, until the recent coming to California of Professor W. M. Davis, the father of physiographic study in America, was but little appreciated.

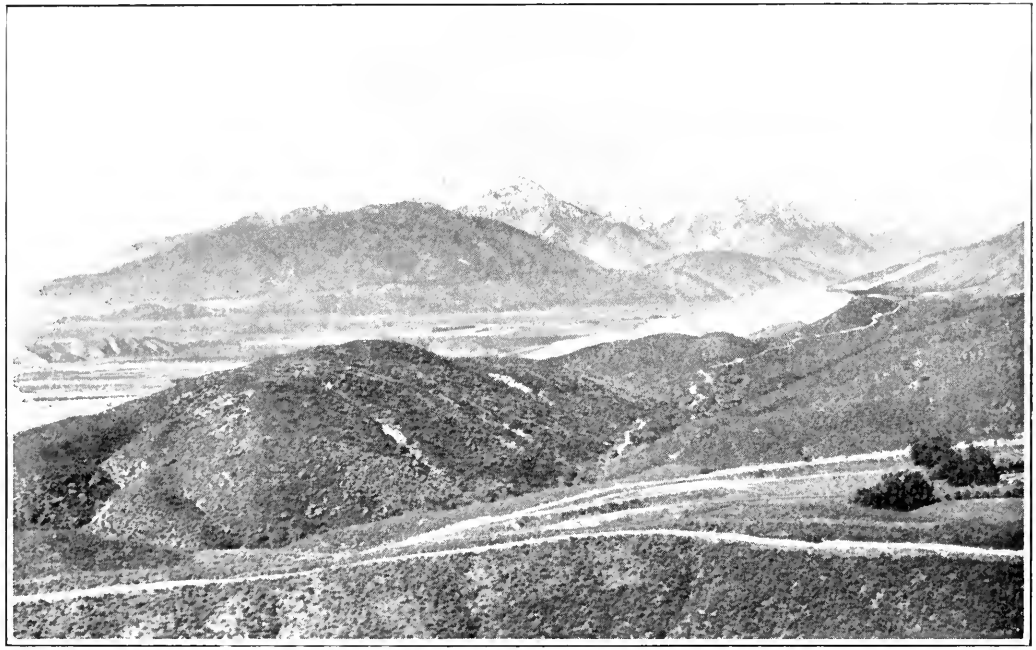
along the north side of the Orocopia Mountains, the south end of McCoy Mountain and through the north side of the Chuckwalla Mountains. For thirty miles of its course south of the Eagle Mountains this supposed rift follows a long, ribbon-like valley suggestive of a graben trough.

RELATIONS OF THE TRANSVERSE STRUCTURE OF CALIFORNIA TO THE GREATER TRANSVERSE BELT

The east-west structure lines of Southern California are only parts of the greater transverse structure zone which extends across the entire American Continental Mediterranean regions, as I have previously described. The continuity of the belt in California is cut across in several places by the paths of the later northwest systems, notably at Los Angeles, Cajon Pass and probably at a point near the Colorado River. In places its continuity is buried beneath Pliocene and Pleistocene sediments. These facts testify to the relative antiquity of origin of the system, which was probably at least as far back as pre-Pliocene time. Renewed movement has taken place on some stretches in Pleistocene time, especially along the Santa Monica and Cucamonga sections.

THE NORTHEASTERLY TRENDING BELT OF FAULT LINES

Northeasterly trending faults also occur in Southern California, but with a few conspicuous exceptions such as that of the Garlock fault, they are mostly of the "interior" kind, and do not constitute topographic boundaries as do those of the other directions described. The great Garlock fault of this direction is one of the most conspicuous master lineaments of California. The



CAJON PASS AND SAN GABRIEL PEAKS FROM ARROWHEAD
Every lineament a rift line (Putnam Studios)

location and description of this feature, originally described by Hess, have recently been more fully set forth in a paper by Dr. Noble.[1]

This fault extends in a northeast direction from the San Andreas Rift east of Tejon Pass into Utah along the boundary between the southeast side of the Tehachapi Highland and the northwest side of the great Mojave Desert. Many short, parallel northeasterly grooves suggestive of northeast fault lines are found in the San Gabriel, Puente and Repetto Ranges and in the west side of the San Jacinto Highlands.

Suggestions of northeast-southwest extending faults through some of the larger mountain passes are also found. A very long and strong fault of this kind probably passes from the Saboda Hot Springs northeastward through the San Jacinto Mountain beneath the alluvial formations of the east end of the San Gorgonio Pass, and through the Morongo Valley. Parallel faults of this direction also appear in the physiography of the northwest side of the San Jacinto Mountains and the Morongo Valley.

There is also some evidence that structure lines of a northeast trend—either folds or faults—may occur beneath the surfaces of the Foothill and Downey Valley Plains, as buried continuations of the saddles between the individual domical hills of the bordering Puente, Montebello and Dominguez Ranges.

The northeast trends are sometimes expressed by foldings. The Los Angeles, San Gabriel and Santa

[1]Noble, L. F. "The San Andreas Rift and Other Desert Activity in the Desert Region of Southeastern California." Carnegie Institution Year Book 25, Washington, 1927, called attention to the resemblances between this fault and the San Andreas Rift.

Ana Rivers flow seaward across the Downey Plain to the coast through synclinal gaps in the Santa Monica, Repetto and Puente Mountain Ranges and also in the Dominguez Range. The Los Angeles River leaves the San Gabriel Valley through a synclinal pass in the city limits formed by the opposing ends of the Elysian Park and Repetto Hills. The San Gabriel River likewise leaves the San Gabriel Valley between the plunging ends of the Puente and Montebello folds. The Santa Ana Pass is also a similar synclinal gap in the mountains. The mouths of all these rivers reach the sea through synclinal gaps of the Dominguez Range. In other words, all of the streams pass through the ranges which cross their paths through synclinal gaps.

Kew has shown upon the portion of his map north of Soledad Canyon many small parallel faults of northeast direction which bend eastward, and also a conspicuous one which extends southwest from Lang to German Canyon. Some inferior northeast faults also cross the Santa Monica Mountains.

Other northeast faults of considerable lengths are shown on Kew's map along the lower portions of the Big and Little Tujunga Canyons and near the west side of the San Fernando Valley. Suggestions of faults of this trend are seen mostly east of the latter locality along the south side of the San Gabriel Range, as far east as Lytle Creek Canyon.

A peculiarity of the northeast-trending faults is that they often occur as short parallel segments between major faults of opposite directions, like the rounds of a ladder between its side rails. It appears as if they had been cut across by transecting faults of the

other directions mentioned. Such has been the case along the south sides of the San Gabriel and Puente Ranges, where the northeast structures have been cut across by the Cucamonga and Puente faults respectively. At present I have no idea as to the initial age of this type of faulting. Its presence in the highlands and absence in the plains suggests that it is relatively old; apparently older than the east-west group and many of the northwest faults.

THE SECOND BELT OF NORTHWESTERLY FAULTS

The next structure belt to be described consists of many master faults mostly of remarkable length, continuity and rectilinearity, of which the Cadiz, San Jacinto, and Elsinore rifts are examples. Like those of the first described northwest extending belt (in which I arbitrarily included the Catalina and Coast Range groups) and from which the members of this group are only doubtfully separated, they have northwest-southeasterly directions. In fact I make no definite assertion that the two groups are separated from each other.

The master rifts of this belt occur parallel to one another at intervals of from five to twenty miles in the wide country between the Colorado River just north of Blythe, on the east, and the San Diego County coastal border on the west. They parallel the supposed faults of the submerged Catalina trends which have been arbitrarily placed in first northwest trending group, but which might equally as well be placed with this second group. The total width of the belt in California is about two hundred miles. It is difficult at present to assign it a definite length, for only a portion

of the northern end lies in the United States. On the desert side the fault lines of the belt extend southeastward to and across the Mexican line. Its greatest length in California is over two hundred seventy-five miles and it extends an unknown distance into Mexico —probably to and beyond the Isthmus of Tehuantepec. On the Pacific side the master faults of this belt apparently extend southeastward for 150 miles in Southern California, and for an indefinite distance into Mexico. The width of this belt is not limited to California but it may extend still farther east across Southern Arizona, New Mexico and into Trans-Pecos Texas and for an equal distance across Northern Mexico.

Some members of the belt on the Desert side apparently terminate abruptly against the Garlock fault at the northwest. Others like the Mill Creek and San Jacinto rifts branch off southward from the San Andreas rift, while still others appear to be southward continuations from the flexed structures of the Ventura Ranges.

Everywhere the faults show a similarity of character, each making a strong lineament of the physiography—fault scarps, often old and worn, mountain and valley borders, or linear grooves and valleys in the face of the landscape.

The group includes at least ten master fault lines of unusual length and topographic conspicuity and apparently of profound and mostly normal vertical displacements. Beginning at the east and proceeding southwestward these may be enumerated as follows: Cadiz, Newberry, Old Woman, Mill Creek, San Andreas, San Jacinto, Reche Canyon, Grapevine, Elsinore, San Onofre and Inglewood faults.

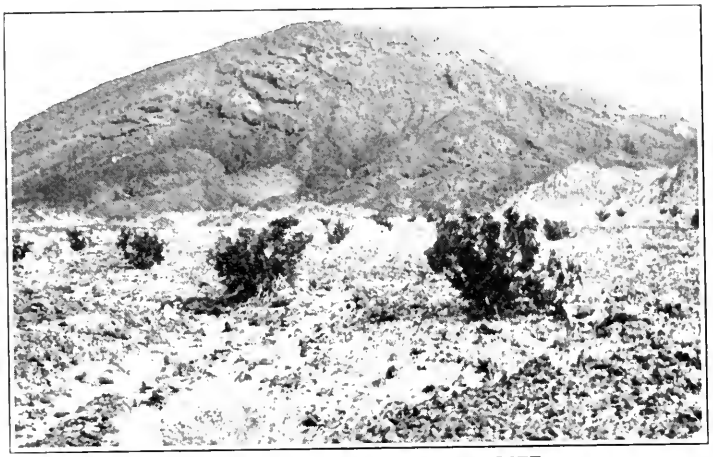
The location of each of these must be briefly indicated and defined, inasmuch as several of them have heretofore never been mapped or even mentioned. Uncertainty as to the exact number is due to the lack of more detailed research, especially on the Desert side.

THE N0ORTHWEST STRUCTURES OF THE DESERT SIDE

Far out on the desert side, thanks again to the new maps and relief models thereof made by the City of Los Angeles, we get new light upon this second southwest system of structures, for there one will find some wonderful examples of the northwest-southeast rifts not hitherto described, and of which there are at least two principal ones, if not more, as indicated on Plate I.

THE CADIZ AND NEWBERRY FAULT LINES

The Cadiz and Newberry faults, with a chain of great trough-like valleys between them, are about twenty-five miles apart and run southeastward from the northeasterly-extending Garlock fault near Randsburg and Mojave respectively for distances of one hundred and fifty miles in California to the Colorado River, which they cross on either side of Blythe. Between these two more conspicuous, parallel faults is a chain of elongated, lower-lying, desert valleys which are followed by the Santa Fe Railroad between Barstow and Blythe and which I herein refer to collectively as the Valleys. These Valleys apparently represent a vast structural trough between the adjacent master fault lines mentioned. They are the easternmost of a second belt of northwest extending faults supposedly of Pleistocene and older ages which are successively encountered in crossing Southern California



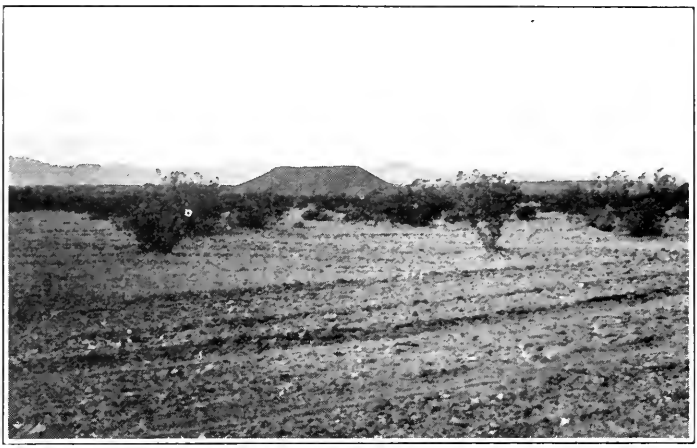
CRATER AT LAVIC NEAR CADIZ RIFT
The molten sub-crust sometimes reaches the surface along fault line

from west to east. Together with the great structural trough between them and accompanying phenomena, they are objects of great interest worthy of detailed study.

THE CADIZ FAULT

The northwest-southeast ranges of the region mentioned consist of several parallel ribbons of fault block structures of similar directions, and chiefly dominated by two major lines which I may term the Cadiz and Newberry faults respectively.

The northernmost of the two faults mentioned is a narrow fault zone which may be named the Cadiz fault. Its path is shown by the notches which cut across the south ends of the desert ranges of the Great Basin (including those known as the "Bristol Peaks," "Old Dad," "Marble" and "Old Woman" ranges), and by the alinement of the south ends of these ranges



CRATER AND LAVA FLOW NEAR AMBOY

themselves. The topography indicates that this fault line, about which no more is known or has been given than is stated here, is a zone of step-down faults descending to the great Amboy Trough.

The western end of this northwesterly fault apparently ceases at the Garlock fault thirty miles southeast of Trona. No attempts have been made to ascertain the details of its extent southeastward into Arizona and Mexico.

The line of the Cadiz fault extends southeastward from the angle of the Sierra Nevada near Inyokern to the Colorado River just south of Riverside Mountain.

Between the line above mentioned and the great Pinto Mountain east-west fault there is a wedge-like triangular area of desert country that narrows to the east from the Antelope Valley embayment of the Mo-

jave Desert towards the Colorado River. This area includes several long and narrow ranges of northwest-southeast direction which project above wider valleys of desert waste: the Bristol, Bullion, Iron, Granite, Sheepshead and other ranges. The relationship between the ranges, valleys and fault lines of north-south, east-west and northwest-southeast trends which meet and interfere with one another here may only be appreciated by studying the new maps.

THE NEWBERRY FAULT

About thirty miles southwest of the Cadiz fault and almost parallel to it there are evidences both in the stratagraphy and topography of another great fault. This extends through the north border of the extensive highland known as the Bullion and Sheep Hole Mountains. It also passes the north end of the Coxcomb and Palen Ranges and the south end of Granite Mountain. This line, too, is a narrow zone of faults which down-step to the north so as to oppose the south throws of the Cadiz faults. The topography suggests that it, too, is accompanied by a subordinate parallel line of faulting, about five miles distant to the north of the main line.

Like the Cadiz fault, the Newberry fault apparently begins at the Garlock Fault on the northwest and extends southeast into Arizona. It intercepts the Colorado River somewhat south of the town of Blythe.

THE AMBOY TROUGH

The path of the Santa Fe Railway from east of Barstow southeastward to Blythe on the Colorado River finds a natural "easiest way" by following a chain of desert valleys which lie between the Cadiz and New-

berry fault lines above described and which are more or less connected structural depressions. Although reconnoitered several times by the writer, little is as yet known about them. Apparently the trough is a series of down-sags between the fault lines mentioned. The depth of sinking of the valley block and the fault displacements on either side are relatively extensive. Along the sides of the valley and out of its bottom several well preserved volcanic craters rise, accompanied by flows of ropy, basaltic lava as may be seen west of Amboy and at other places.[1] The latest of these lava flows follow and fill drainage ways of the valley floors. On this account they may be adjudged to be quite modern.

Extensive "dry" lakes also occur in the Amboy trough, two of which are known as the Amboy and Bristol Lakes. The former has a surface of gypsite and is the source of much of the commercial gypsum used in Los Angeles. Towards the southeast end of that portion of the Amboy Trough which lies in California, its Arizona continuation not having been studied as yet, several small lost ranges occur. These have northwest-southeast trends, and may be secondary structural blocks. Near the Colorado River in California the paths of these northwesterly extending faults intersect with the faults of the east-west or transverse belt, thereby adding further interest to the geology of the region.

THE OLD WOMAN FAULT ZONE

A zone of the northwest-southeast faulting passes

[1]Some fifteen years ago the writer visited, studied and mapped some of the phenomena of the Cadiz and Newberry faults and Amboy Trough and adjacent ranges.

along and through the northeast side of the San Bernardino Plateau, giving the scarped character to a part of that side of the highland, and from thence southeast through the Morongo (Little San Bernardino) Mountains. The writer has observed this zone of parallel rifts near Old Woman Springs and Francis Vaughan has described it and shown it upon his map.[1] From the results of one brief reconnoissance and from map studies, it is probable that there are three parallel faults in this general vicinity, one each of which runs near Old Woman Springs, Rattlesnake Canyon and Brush Canyon. The two last mentioned apparently extend southeast into the desert for an indefinite distance along the north side of the elongated Little San Bernardino Highland block. Volcanic effusions of basic lava accompanied these lines of faulting in places around the northeast and east ends of San Bernardino Plateau.

A VARIATION IN THE PLAN

One encounters in the region of San Gorgonio Pass a locality where there is a variation in the simple plan of the fault pattern of this belt. Certain rifts of easterly trend apparently branch off from the prevalent northwest course of the San Andreas Rift. Of these the Mill Creek, Raywood and Morongo Reservation faults are conspicuous illustrations.

Proceeding from the Old Woman Fault southwestwardly towards the coast there are several other master faults of this northwesterly system, which occur at intervals of from ten to twenty miles. These have been reconnoitered, but as yet not sufficiently sketched in detail. The most evident ones are the Mill

[1]Geology of the San Bernardino Mountains. Univ. of Cal., Bull., Dec. 1922.

Creek, the San Andreas, the San Jacinto, Reche Canyon, Grapevine Canyon, the Elsinore, San Onofre, and the Inglewood faults respectively.

SAN GORGONIO PASS

The pass is itself a wonderful example of the meeting and crossing place of rifts of great displacement, of several directional groups and of different ages, which contribute to the making of one of the most beautiful and interesting pieces of earth architecture in America. The oldest of the rifts which compose this complex were probably faults of the north-south directions which outlined the west side of the Colorado depression at the east end of the Pass, and probably was of pre-Miocene age. Movement was revived along it in Pleistocene times as probably indicated in the Whitewater and Palm Springs Faults. Next in age probably were the northeast-extending Raywood, Potrero, and Morongo faults at the southeast end of the mountain. Then followed the east-west-trending faults of the Transverse Belt—the Banning and Lawrence faults already described—which are of Miocene or earlier age. With their making the great east-west pass between the guardian summits of San Jacinto and San Gorgonio which now border it was first opened across the pre-existing north-south fault scarp of the west side of the Colorado depression. Then came the northwesterly-extending San Andreas rift of Pliocene and Pleistocene time. This cut diagonally southeastward across the entire group of older faults as shown in the figure. This may be an older fault line along which there probably was a revival of movement, just as a few present-day shocks are the sur-

viving after-effects of the greater movement along it in Pleistocene time.

THE SAN ANDREAS RIFT IN SAN GORGONIO PASS

The course of the San Andreas Rift adjacent to and along the southwest side of the San Bernardino Plateau and through the San Bernardino Valley and San Gorgonio Pass is recorded by one of the most beautiful and majestic fault scarps in California. This feature is visible for forty miles between Cajon Pass and the Colorado Desert and has many lovely towns and cities nestled near its foot, including San Bernardino, Redlands, Beaumont and Banning. The escarpment rises for more than a mile above the plain of the San Bernardino valley at its southern base and to a nearly uniform skyline which is termed the "Rim of the World." It is indeed a wonder feature, the beauty and majesty of which is enhanced by many subsidiary features, such as secondary rift lines, talus fans, faceted salients, terraces, cross-cutting river-canyons and escarpment erosions, all of which will undoubtedly some day be described in detail by others.

This portion of the rift is not a single, simple fault line, but is a more or less complicated zone of parallel faults which not only attend the immediate base of the escarpment, but are found in the valley below. Its intricate details, we understand, are being worked out by Mr. Noble, but his results are not available.

The foot line of the scarp, which may be tentatively considered the main rift, sends out several branches as it approaches the San Gorgonio Pass and as it passes through its north side. One of these is known as the

Mill Creek fault. It branches off in a more easterly direction from the main rift at some point east of San Bernardino, as will presently be more fully described.

The main rift southeast of Mill Creek closely follows the south side of the Mill Creek Range, where its presence is indicated by a steeply-sloping escarpment of tremendous proportions, which rises between altitudes of four thousand and eight thousand feet, and is marked by wonderful truncated facets, as may be seen north of Forest Glenn and Beaumont. To the east of Pine Bench several other major faults occur, apparently as easterly branches of the main rift, and are accompanied by great valleys through which flow the headquarters of San Gorgonio Creek. One of these may be termed the Raywood Fault and another, which passes through the north end of the Morongo Indian Reservation, I have named the Potrero Fault. Southeast of the reservation the continuation of the San Andreas Rift towards Whitewater Creek is complicated by its junction with the Banning and other faults. This I have not worked out in detail.

The successive eastward branches from the main fault along the southwest borders of the San Bernardino Plateau have detached long and narrow physiographic blocks from it. These lie apart as outlying ridges, much after the manner of partially severed slices from the end of the main highland.

MILL CREEK FAULT

The Mill Creek branch of the San Andreas Fault arises along the southwest escarpment of the San Bernardino Plateau east of San Bernardino and proceeds in a slightly south of east direction along the south side of the plateau summit towards the north-

west end of the Colorado Depression, which it intercepts near the mouth of Morongo Canyon. Its course is marked by the long, steep, deep and straight valley of Mill Creek, which separates the summit range of the plateau from a narrow ribbon-like range on the south, lying between the Mill Creek and San Andreas Rifts and which may be called the Mill Creek Range. This range lies between the summit of the plateau and the observer when he looks northward from the line of the Southern Pacific Railway through San Gorgonio Pass. The displacement along this fault is some three thousand feet or more to the southwest.

The eastward continuation of the Mill Creek Fault passes by the little Indian Reservation marked "Hog Ranch" on the southeast corner of the San Bernardino topographic map of the United States Geological Survey. From the latter point eastward the fault follows the south side of the Little San Bernardino Mountain for an indefinite distance. These mountains make the northern boundary of the northwest end of the Colorado Depression.

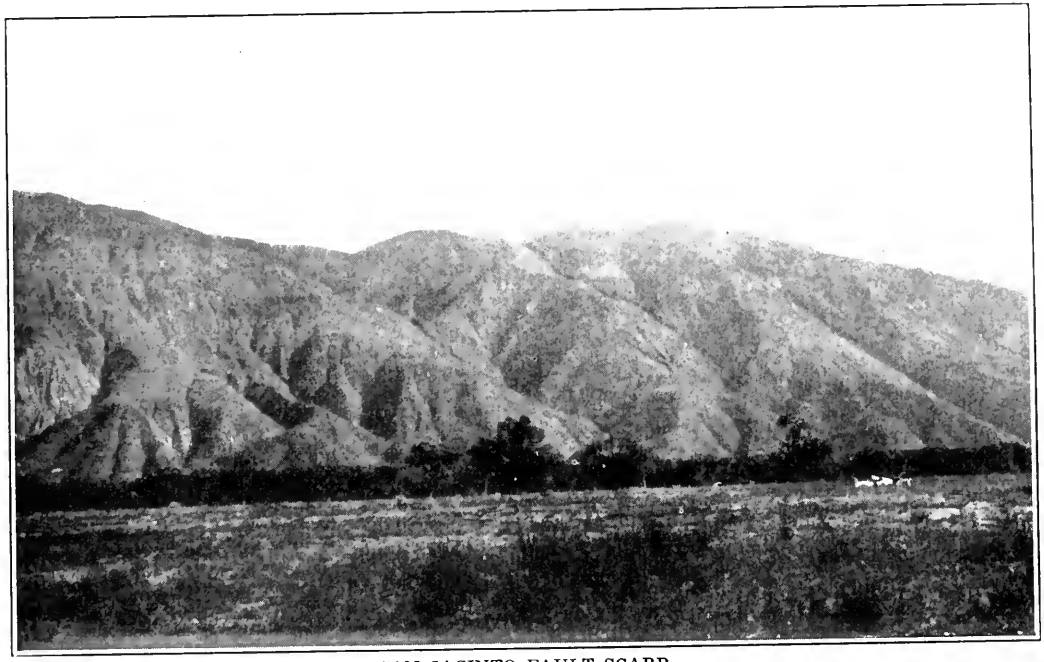
This fault is one of the great master faults of Southern California. Its exposure likewise is the highest and northernmost of a series of master faults between the San Gorgonio summit of the San Bernardino Plateau (altitude nearly 11,485 feet) and the floor of San Jacinto Valley (altitude 1600 feet) which branch out eastward from the main San Andreas Rift Line and step-down to the southwest with a collective downthrow of some nine thousand five hundred feet.

THE SAN JACINTO RIFT

Continuing southwestward from San Gorgonio Pass across the several rifts, one again encounters the vari-

ous faults and phenomena of the northwest trend. The first of these is the San Jacinto Rift, which is one of the largest and best defined of all the master faults of Southern California.

Its course, with the exception of a short stretch across the Ontario Valley and the Badlands Range, constitutes the strongly emphasized scarp lines and topographic borders of the southwest margins of the Badlands and San Jacinto Ranges. It branches off from the main San Andreas Fault zone in the north side of the east end of the San Gabriel Highland and follows the course of Lytle Creek Canyon through the mountains into the San Bernardino (Ontario) Valley Plain. Its presence across the last mentioned feature is also indicated by the southeast course of Lytle Creek. The fault diagonally crosses the San Timoteo (Badlands) Range east of Reche Canyon to a point north of Moreno, from whence it follows and corresponds with the south border scarp of the combined Badlands and San Jacinto Ranges as far as Saboba Hot Springs, near San Jacinto. Along the portion of its course between the Jack Rabbit Trail and Saboba there are many hot springs. There are also several parallel rift-lines and step-down benches along this portion of its course. These suggest a series of upward movements to the northeast. The zone divides into two well-defined, adjacent and parallel lines from San Jacinto River southeast. The main and westernmost of these is traceable on southeastward, via Hemet, across the spurs of the Peninsula Highland into the desert near Calexico and Mexicali, and on indefinitely into Mexico, where its course is marked by near-by



SAN JACINTO FAULT SCARP
Two or more uplifts

mud volcanoes and now quiescent but recently active, true volcanic craters.

So far as I have observed the displacement along the lines is subvertical and amounts to a step-down of over one thousand feet to the southwest. This fault line is a part of the line of greatest seismicity in Southern California. It is the site of the most frequent and the severest of the earthquakes that have occurred in Southern California in late years, the shocks of which are sometimes felt in and accredited to Los Angeles, although the nearest approach of this line to the latter city is over eighty miles.

THE ELSINORE RIFT

Another conspicuous scarp-making master-fault zone of great displacement extends from just west of Pomona southeast through the Elsinore Valley and from thence on into Mexico. One hundred and fifty miles of its path lies within the State of California, and its continuation into Mexico is conspicuously visible for at least fifty miles south of the international border, beyond which knowledge of it is lost in the geologic terra incognita of that country. It crosses the Mexican border twenty-five miles west of the San Jacinto Fault. Its course almost exactly parallels those of Cadiz, Newberry, San Jacinto and other fault line members of the group. It is even possible that its northern end does not cease at Pomona, but, that after temporary concealment beneath the more recent formations of the valley plain, it may continue into connection with the great San Gabriel Fault of Kew, which extends northwesterly through the San Gabriel Highland.

Altogether the Elsinore Fault is one of the marked

physiographic lineaments in Southern California. Several hot springs also occur along its course, and it has provided several minor shocks in historic times.

The course of this fault zone, which in places is composed of parallels, is marked by infacing escarpments and a great depressed valley trough or graben. Among the valleys which owe their existence to it may be mentioned, beginning at the northwest, the Chino Creek Basin, the Elsinore Basin, which latter includes the continuous valleys of the Temescal, Elsinore Lake and Temecula drainages, the San Luis and Banner drainage valleys and the great Vallecito and Jacuba valley embayments, which extend as northwestward indentation from the desert into the east edge and summit of the plateau. All of these features are adjusted to the lines of the rift zone.

This rift is associated with the border escarpments of many adjacent highlands which are uplifted blocks along its course. Some of these face to the northeast and others in opposite or southwest directions, suggesting a condition which is technically called rotational. Among the east facing features are the east borders of the Puente Hills, the great, titled block of the Santa Ana Range, and the gigantic escarpment which leads down from the summit region of the Peninsula Highlands to the desert in the cross section along the Mexican border. The several conspicuous westfacing escarpments along the line include those of the Agua Tibia, Volcan, Santa Ysabel and Vallecito Mountain blocks and also the belt of country between the San Jacinto and Elsinore Rifts at the north end of the Peninsula Ranges, which has been termed the "Perris Peneplain." No detailed studies have been made of

the structure of this rift line, although I have closely reconnoitered it.

In southern San Diego County there are two, if not three, north-south extending faults which terminate to the northward against the line of the Elsinore Rift. One of these passes near Campo and another near Jacuba. Their southward extent crosses the border into Mexico.

THE LAKEWOOD RIFTS OF THE PERRIS PENEPLAIN

Many subordinate interior fault lines lie between the Elsinore and San Jacinto Faults and are parallel to them. These occur in alternations of long ribbon-like strips of level plains and mountains some twenty-five miles wide, which extend southeastward through the northern part of the Peninsula Highland region, or the "Perris Peneplain," lying between the San Jacinto and the Santa Ana Mountain blocks of higher altitude on either side of it.

The portion of the Perris Peneplain above mentioned is not a true peneplain of base leveling erosion, but is composed of several ranges and valleys which are alternately up-and-down thrown blocks between parallel fault lines of the Northwest System. Some of the monadnock-like, granite hills, of which the Lakewood Mountains are the most conspicuous members, rise one thousand feet above the surrounding level of the San Jacinto Valley, towards a common level of two thousand six hundred feet. The elongated belts of hills are also checkerboarded by minor cross rifts.

The writer at present entertains the tentative hypothesis that the summits of the hills of the Perris Peneplain belt are the residuals of a former horst-like

plain of granite and metamorphic rocks which extend indefinitely southeastward, and that the valley areas on the San Jacinto and Elsinore sides thereof are graben-like troughs or sunken blocks.

THE SAN ONOFRE FAULT

Another master fault line which is of some magnitude, though relatively less conspicuous than some of those mentioned, follows the tilted fault-block down as the San Onofre Hills, in northeastern San Diego County, as has been pointed out by Woodford.[1] The regional topography contains the suggestion that this fault might be continued northward to the Santa Ana River.

THE INGLEWOOD FAULT

A line of faulting follows the course of the Dominguez Range, Southern California's newest and greatest wealth-producing mountain chain, from the south side of the Santa Monica Mountains on the north, to and beyond Balboa to the southeast. This fault closely follows the coast line in its extension southeast from Balboa toward San Diego.

This rift line consists of one or more closely-spaced faults which usually follow the southwest side of that portion of the chain southeast of Hawthorne. It passes through the center of Inglewood Hill to the northwest of Inglewood, where the course is marked by a deep summit-valley and one or more parallels on the east. The aggregate displacement of the main fault in the Baldwin Hills is at least three hundred feet to the west, as has been ascertained from oil well logs.

[1]Geological Bulletin, University of California, vol 15, No. 7. 1925. This valuable paper contains instructive description of alternations of rising and sinking of individual fault blocks.

While the fault line is chiefly expressed by the surface contours, there are instances of exposed contacts, as in the road-cutting on the Associated Oil Company's ground on Inglewood Hill and in the old sand pits on the south side of Signal Hill at Long Beach. This faulting is due to stresses along the line of the folding of the Dominguez Range. Some of the small shocks which Los Angeles feels now and then are derived from this line of faulting.

FAULTED STRUCTURES OF THE SUBMERGED BENCH

The contour map of the submerged border-land of Southern California (which is, perhaps incorrectly but for the want of a better name, termed "the Continental Shelf" upon our map, Plate I) somewhat strongly suggests the existence there of several alternations of uplifted and down-thrown ribbons of faulted structures of the northwest trending types. These we have designated upon the map as the Catalina, San Clemente, San Nicolas and Submerged Ranges, and Troughs No. 1, 2, 3 and 4, respectively. The graben-like character of trough No. 2, between the Catalina and San Clemente Ranges, is very apparent, and has been previously noted and illustrated by Tabor.[1] As cited on a previous page I have arbitrarily placed these features in the first group of northwest structures.

There are strong suggestions of several more or less parallel faults of the northwest-southeast groups, which may cut slightly diagonally across the older north 40 west trends of the submerged bench, as indi-

[1] "Fault Troughs." Journal of Geology, October-November, 1927.

cated by the topography of the northeast sides of Catalina and San Clemente Islands.

MORE ABOUT THE SAN ANDREAS RIFT

The San Andreas Rift as an entirety, has been previously discussed as a portion of the boundary of the San Bernardino Plateau, in our brief description of the San Gorgonio Pass and under the headings of the "Line of Greatest Seismicity." Likewise, we have referred to the previous and more detailed writings on the subject by Fairbanks, Noble and others.

The California portion of the line is divisible into two distinct sections each with different directions and details of occurrence. The portion of the northernmost of these in California, which I herein call the Northern Segment, is some three hundred and fifty miles long. It extends from Cape Mendocino to a point near the thirty-fifth parallel of latitude in the southwest corner of Kern County, about ten miles south of Maricopa, and near the junction of the counties of Kern, San Luis, Santa Barbara, and Ventura. This segment has a trend of north 40° west and is a member of the Coast Range belt of fault lines of similar direction which parallels the coast of California to the north and which has as yet no defined analogy in Southern California. (See Plate III.)

In so far as the geographic relations of the two sections are concerned, both may be considered as accompaniments of the structural features which I have herein termed the Coast Range Belt and the San Andreas-Puente Belts respectively, along which the rift breaks up into branches as I have shown on Plates II and III.

NORTHERN SECTION OF THE SAN ANDREAS RIFT

The writer claims no great personal familiarity with the northern section of the San Andreas Rift, although his experiences with it have been as many as some of those who write about Southern California overconfidently. Its features have been rather fully described in the geologic literature and worked out in great detail in places. Its general occurrence is shown on the maps of the Earthquake Commission and the Earthquake Map of the Seismological Society. These details will be seen to differ greatly from those of the Southern Segment.

The southern part of the Northern Section is merely the easternmost member of a wide belt of rifts which I have termed the Coast Range Belt of structures. Going northward its course first follows the elongated Carrizo Plain. North of the latter it becomes associate with a narrow zone of parallel faults which pass by or near San Lorenzo, Lobo, San Benito, and Hollister. The elongated Salinas Valley lies to the west of its path.

The San Andreas Fault line proper passes eight miles southwest of the center of San Francisco as one of a narrow belt of similar rifts which extend from the sea border as far east as Berkeley, the whole constituting a narrow, faulted zone of more or less active seismicity according to the Fault Map of the Seismological Society.

THE SOUTHERN SECTION

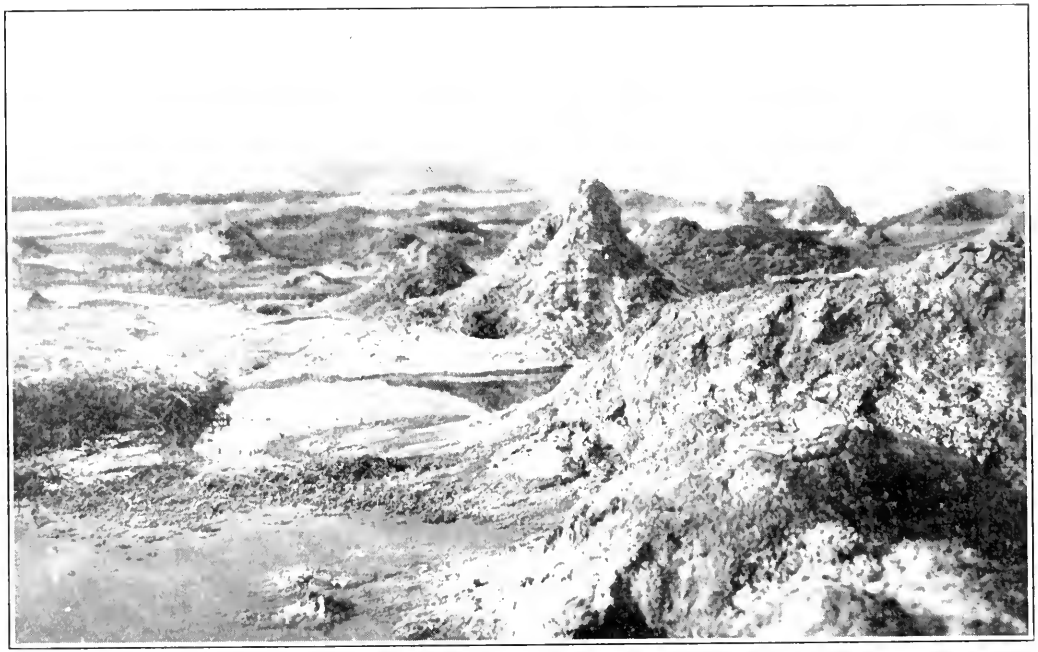
The Southern Section of the San Andreas Rift begins at the bend several miles south of Maricopa and follows a course of south 56° east for two hundred

and twenty miles towards the Mexican boundary near Yuma. Its actual course is very conspicuous for approximately one hundred and fifty miles of this distance, to near the east end of the San Gorgonio Pass (Morongo Indian Reservation), near Banning, where it branches and beyond which the identity of its main stem is lost in the structural complexities of the pass itself and beneath the sand covered floor of the Colorado Depression.[1] Regardless of publications to the contrary, the best guess is that it passes through the lowest points of the Coachella arm of the desert and the Salton Sink, near the mud volcanos, and on toward Yuma. The definite trace of the western half, from south of Maricopa to Cajon Pass, the section between Cajon Pass and Whitewater, and the indefinite trace of the eastern half of this southern section of the San Andreas Rift are herein termed the Valyermo, the San Bernardino and the Desert segments respectively.

I have reconoitered the entire length of the Southern Section from its west end to Yuma and studied some parts in close detail. Likewise, I have had the benefit of some of Noble's observations of former years and his recent publications. As he has shown, it is by no means a simple fault line feature, but in places it is a complex zone of narrow parallel blocks some of which have been elevated and others depressed. Furthermore, great branches like the Mill Creek and San Jacinto Rifts lead divergently away from its main trace.

That portion of the San Andreas Rift between the "bend," south of Maricopa and Cajon Pass, above

[1]Brown, John F. Fault Features of the Salton Basin. Journal of Geology, 1922.



MUD VOLCANOES NEAR RIFT LINES, SOUTH OF MEXICALI.
Crater in background

termed the Valyermo Section, makes the northern boundary of the San Andreas-Puente Belt.

NATURE OF THE FAULT MOVEMENTS

Vertical movements along the Southern Section of the San Andreas Rift have resulted in the production of many of the master physiographic highlands, valleys and other lineaments of Southern California. To them are due the sharp, rectilinear scarp-lines of the northeast side and through the northeast end of the San Gabriel Highland, the southwest side of the San Bernardino, and the north end of the San Jacinto master highlands, as well as the southwest border of the Mojave Valley and the north end of the great Gulf of California (Colorado) Depression.

Lateral (horizontal) movements like that which accompanied the San Francisco earthquake in 1906 may probably also have taken place along this Southern Section of the San Andreas Rift in past geologic times whereby the northeast or San Bernardino Highland side has been moved southeasterly, and the southwest, or San Gabriel side, to have moved northwesterly. This has been suggested by the relative positions of these two mountain regions as shown on Plate I, and other related conditions.

POSSIBILITY OF TWO FAULT LINES

On the whole I am prone to inquire if the Northern and Southern Sections of the San Andreas Rift may not consist of two ancient and formerly distinct faults, which intersected at the region of the bending south of Maricopa. There are suggestions in the physiography which might lead one to infer that the more westerly end of the Southern Section may have rela-

tionship with the ranges of San Luis Obispo County of similar trends. On the other hand, the bend may have been an accompaniment of the great buckling which I described. To solve such problems will require much field work and study.

RELATION TO THE GREAT MOUNTAIN PASSES

The great gateways into Southern California known as the Tejon, Cajon and San Gorgonio Passes are all located along the line of the San Andreas Rift at positions where it is intersected by faults of other directions. The path of the rift also cuts across many other lines of faulting, especially those of the older east-west belt like the Bouquet and Cucamonga Rifts.

THE SAN ANDREAS-PUENTE BELT OF FAULTING

For reasons which will be apparent, I have deferred until now the task of describing a peculiar structural feature which I will term the San Andreas-Puente Belt of faulting. This, in turn, is a portion of a great flexured belt or buckle which has dominated the structure of part of Southern California. It embraces a wide and diversified strip of country one hundred and forty miles long which extends from the "bend" in the San Andreas Rift, at the west end of the Valyermo section the Cajon Pass, and lies between the said rift on the northeast side of the San Gabriel Range and the Puente Fault line on the southwest side of the Puente Range. Between these main bordering faults there are several parallel fault lines, some one of which practically defines a border of the Verdugo, Repetto and Puente Ranges or lies within the area of the San Gabriel Highland. Its width in cross-section

averages about thirty-two miles and it trends in a direction of about north 65° west. A distinguishing feature of this belt is the fact that its trends are intermediate between those of the Northwest and East-west systems. They are some fifteen degrees more westerly than the almost true-northwest trends of the Northwest system of the San Jacinto type and more than twenty-five degrees more westerly than those of the true Coast Range system of Northern California.

The master faults of this belt give origin and outline to the following physiographic features: the San Gabriel Range, most of which is a complicated, uplifted block between the boundaries of the San Andreas and Sierra Madre Faults; the Puente, Washington, Repetto, Montebello and other hills of folded structures which are bounded on one side by such structures; and corresponding lowland features which have also resulted from these fault displacements. Among these are the La Canada Valley trough, the Bottle-neck Pass at the southwest end of the San Fernando Valley, and possibly, but not proved, the Culver City Pass in the Dominguez Range.

The belt is characterized by the occurrence of the following known parallel master rift lines or zones, given in sequence from north to south respectively; San Andreas Rift on the northeast side of the San Gabriel Range, already mapped and thoroughly described by others; the San Gabriel and Sierra Madre Faults of Kew[1] in and along the southwest border of the San Gabriel Range; the south side fault of the Verdugo Range; and the Puente Fault zone of Arnold and Eldridge[2], which has been more recently described[3] as

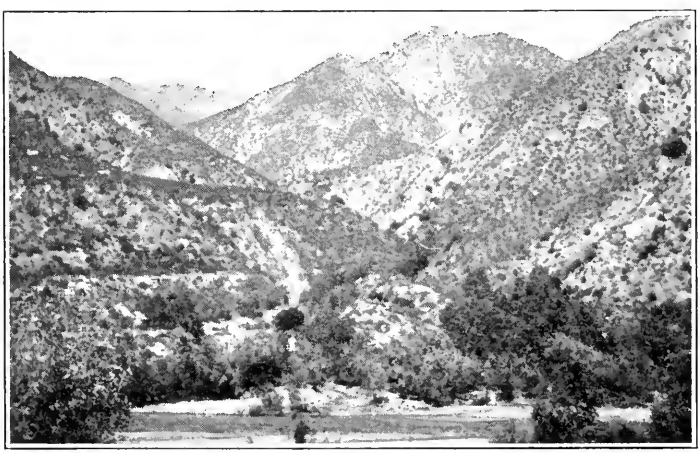
[1]Bull., U. S. Geological Survey No. 753; [2]309; [3]768

the Whittier Fault by English on the south. Besides these there may be many secondary or interior faults within the belt, the details of which have not as yet been determined.

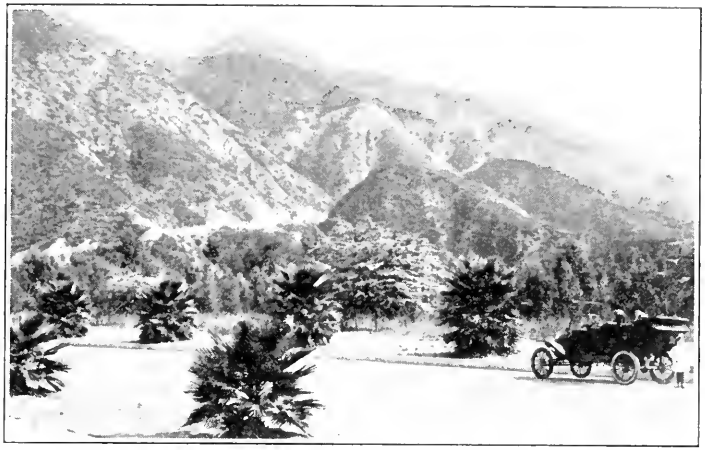
The nature of the San Andreas Fault line has already been described. A word or two must be given concerning some of the other rifts which compose the belt.

THE SIERRA MADRE AND SAN GABRIEL FAULT LINES

Two conspicuous fault lines are found adjacent to the southwest side of the San Gabriel Highland and have been mapped and described by Kew as the San Gabriel and Sierra Madre Rifts. The northernmost of these is the San Gabriel Rift and it lies within the summit area of the San Gabriel Highland block, about four miles from its southwest border. It extends northwesterly from near the town of Sierra Madre



SAN GABRIEL SCARP AND TERRACES OF ELEVATION
MOUTH OF TUJUNGA CREEK



SAN GABRIEL SCARP NORTHEAST OF PASADENA
Showing rifts and kernbuts

through a point just north of Saugus to near Sulphur Peak, in the Ventura Ranges. From this point the course is uncertain. It may curve westerly along the south sides of the more or less continuous Topa-Topa and Santa Ynez Range, or continue northerly through the Castiac Valley, as has been suggested to me by Mr. Hoyt E. Gale.

The Sierra Madre fault follows the edge of the San Gabriel Highland and practically parallels a portion of the San Gabriel Fault. It may be related to a fault line which follows the South Oak Ridge and Santa Susana Mountains of the flexured Ventura Ranges. I refer to Kew's descriptions[1] for facts and details.

THE VERDUGO FAULTS

A large fault or fault zone follows the south side of the Verdugo Mountain block, north of the towns of

[1]Bull 753, U. S. Geological Survey.

Burbank and Glendale, and gives character to the beautiful scenic aspect of the south side of the mountain. Its northwest continuation may bend around into a structure of the flexured Ventura Ranges. This is apparently a zone of step-faulting, as is indicated in the profiles of the mountain salients and the steep slope from the foot of the mountain towards the north side of the Santa Monica Range. The continuity of the fault to the southeast is to be determined.

THE PUENTE (WHITTIER) FAULT ZONE

This is a strongly defined master fault zone originally described by Eldridge and Arnold[1] and later by English,[2] which extends from east of the pass of the Santa Ana River at the north end of the Santa Ana Mountains, northwesterly close to La Habra, Brea and Whittier, and after a short stretch of concealment into Griffith Park at the northwest corner of the Santa Monica Range in Los Angeles. It follows the southwest boundary of the Puente Hills near their southern contact with the north side of the Downey Valley Plain, and probably also that of the Repetto Hills of East Los Angeles, although in places its continuity is indefinite, discontinuous or concealed. The direction of the Puente Fault is about north 65° west, parallel to the course of the Valyermo section of the Southern Segment of the San Andreas Rift previously described. According to English, many different aspects of throw occur along the line. These suggest rotational movements.

[1]U. S. Geological Survey Bulletin No. 309, Washington, 1907.
[2]U. S. Geological Survey Bulletin No. 768, Washington, 1925.

GENERALIZATIONS CONCERNING THE BELT

The country enclosed between the San Andreas and the Puente Rifts constitutes a belt thirty miles in width. Collectively this is a part of the great warp or buckle in the continental trend, to be described on a later page, which also produced the Transverse and Ventura Ranges.

The west end of the San Gebrial portion of the San Andreas-Puente Belt of faulted structures bends northwestward into an apparent continuation with the San Rafael member of the Coast Ranges Belt, and its east end as indicated by the San Jacinto and Elsinore Rifts curves into the so-called Perris portion of the Peninsula Highland, thus making the semblance of a ribbon of nearly continuous supplementary highland about twenty-five miles wide, which includes the San Rafael, the San Gabriel Ranges, and some parts of the Peninsula Ranges. These may serve as a kind of a guide line in estimating the broader flexuring of the region as a whole.

It is also an interesting fact that the course of some faults and flexured Ventura Ranges of the south side of the belt, if projected southeastward, would be in continuation with both the trends of the southwest block of the San Gabriel Highland, between the San Gabriel and Sierra Madre Faults and the Pacoima-Verdugo Ranges.

The complicated details and relations of the western end of the San Andreas-Puente Belt are not sufficiently known to warrant positive assertions concerning them. Some members of the belt bend northward into the Coast Range trends and others strike towards the more

westerly extending ranges of the San Luis Obispo region. The Puente, San Gabriel and Sierra Madre Faults bend westerly into the flexures of the Ventura Ranges and become involved in the complex, and as yet uninterpreted, structures of that region.

The southeast end of the belt, as in the instance of the north end of the San Jacinto Rift, apparently also leads southward and alines with the northwest-southeast faults of the north end of the Peninsula Highland, between the Elsinore and San Jacinto Faults, so that the outline of the belt as a whole is that of a double bend as is shown in the following chapter.

The big bends in the belt where its trends change from north 45° west to north 65° west, and then back to north 45° west again, are great departures from the normal northwesterly continental trends and were apparently produced by stresses in Pleistocene time.

Much more could be said concerning the San Andreas-Puente Belt of northwest structures, and still more may be ascertained concerning it. When fully interpreted these features will throw great light on the geological history of California.

THE GREAT BUCKLE

There are two related instances of curvature in the trends noticeable in the physiography which are exceptions from the normal rectilinear plan and the structure pattern. The first of these is that of the bends of the San Andreas-Puente Belt just described and the second that of the Ventura Ranges, presently to be described. The fact of the matter is, that the two instances mentioned are related, and, together with the east-west structures of the Transverse Belt, are each expressions of parts of the structure of a great buckle

in the continental trend which has taken place in this general region.

From studies of the structure plan it seems to me that in past times, when the great warp or buckle was created that set the Transverse folds and faults crosswise to the normal northerly trends, there were bends, buckles, slidings and overthrusts in that too little understood portion of the Transverse Belt where the various trends seem to meet.

A buckle is a lateral bend. Stand a quire of paper or deck of cards on its longer edge and push from one or both ends, and the leaves (strata) will first bend and perhaps later break and overcrowd along certain lines. This is what has happened along the Transverse Belt of California, the stresses acting in east-west directions. The Ventura Ranges were flexured and horizontal faults occurring along the San Andreas, Santa Ynez and perhaps other lines.

FOLDED STRUCTURES

On previous pages I have shown that the processes of folding and faulting are associated and parallel phenomena in Southern California, although the latter is more in evidence than the former. The rise of a ribbon-like fault block composed of crystalline rocks below and stratified rocks above may bend the latter into folds. Likewise, the lower-lying, crystalline rocks of such a structure, when denuded of the sedimentary rocks, will appear as a faulted block; hence it is most frequently the rule that where sedimentary rocks prevail at the surface, folded structures are most in evidence, and that where the metamorphic and granite materials occur at the surface, the fault block structure is most apparent. Folding of the sedimentary

rocks between floating and drifting blocks of denser rocks may have also been quite possible, as in the instance of the Badlands Range. Some of the causes which have produced the folding and faulting are discussed in a later chapter.

THE SIMPLE TYPE OF FOLDED RANGES

There are several ranges in Southern California in which the simple, elongated, anticlinal type of structure prevails. These are reflected in varying degrees in the physiography. The conformation of physiography to structure varies in accordance with the newness or oldness of the ranges. Conspicuous examples of a close relationship of this type are the Dominguez Range and certain of the Ventura Ranges. The Solomon Hills of the Santa Maria District are another example.

The trends of the simple-fold ranges are usually associated with parallel lines of master faulting and are mostly the products of the same great stresses.

The simple-folded range structure in Southern California sometimes alternates with the synclinal valleys. The lines of folding also usually have sags or saddles in them at more or less regular intervals which divide them into bead-like domes, such as those in which the pools of oil are found, along the courses of the Dominguez and Ventura Ranges.

RELATION TO SURFACE

The physiography of the folded ranges varies in perfection of contour and conformation with the nature of the structure (flatness or compactness of the arches) and in proportion to the ages of the folds. The more perfect and symmetrical folds are found in the newest ranges, like those of the Dominguez and

Solomon Ranges. Sometimes the folding is compact and complicated. In one instance which may be seen in Kew's cross-section of Ventura County, the folds of certain ranges are overthrown (recumbent) and faulted along horizontal planes (overthrust).

In some instances narrow belts, or ribbon-like slivers of sedimentary rocks may be preserved along fault lines in the granitic highlands. Instances of this kind occur in the northeastern and southeastern portions of the San Gabriel Highland as mapped by Noble and Kew respectively, and in the San Bernardino Plateau as mapped by F. C. Vaughan. Such occurrences may be the structurally elevated and degraded remnants of former folds, from which the once overlying mass of sedimentary rocks has been removed by erosion. The close relationship of the folds and faults is further shown by the fact that open folds may sometimes change with time and continued pressure into compact ones.

THE DOMINGUEZ RANGE

The Dominguez Range, previously described, may be taken as the simplest type of a recent mountain fold. Although not entirely so, it is practically a continuous, elongated, anticlinal fold with subordinate domes and sags in link-like succession along it. In places the continuity may be slightly broken with offset ends arranged en echelon. The uppermost strata involved in the arching at the surface are of Pleistocene age, so that we may conclude that the range originated either in late Pleistocene or Recent time. It was in late Pleistocene time, as I show by evidences elsewhere herein given. In general, cross-sections reveal the

structure to be that of a broad, open fold with occasional cross-gaps and accompanied by a line of strike faulting.

The Dominguez Range is paralleled on its south slope for most of its extent by a line of faults (the Inglewood Fault) as described on a previous page. To the north its structure is lost in that of the Santa Monica Range.

The structure of that portion of the chain to the north of the city of Inglewood, including Inglewood Hill, differs somewhat from that portion to the southeast, in that the dominant fault line splits into several members and its course becomes axial instead of lateral. Likewise its extent along the Rincon and Beverly Hills becomes uncertain and obscured by outwash from the north-lying Santa Monica Hills. There are other complications to the north which I am not as yet able to explain.

The Dominguez Range and its attendant Inglewood fault are of the age of the last half of the Pleistocene epoch. It is composed in part of strata of early Pleistocene age, is bordered on its seaward side by late Pleistocene marine strata (the Centinella formation of Tieje) and on its landward (Los Angeles) side by two succeeding formations of continental Pleistocene locustral ("Playa") type of strata. The oldest of these, the Blue Clays of Tieje's section, contain the La Brea vertebrate fauna, while the latest, the La Cienega beds, contain human remains beneath overlying fluviatile, peat-bearing lacustral, Eolian and outwash formations. Hence the folded Dominguez Range and its accompanying Inglewood Fault were chiefly made after the beginning of the Pleistocene epoch and prior to its

RIFT IN DESERT MOUNTAINS, NEAR DALE MINE

close, although surviving movements along the fault still occasionally take place. These facts are further shown in the accompanying figure and stratigraphic section.

SECTION OF THE STRATA

We beg the indulgence of the reader for introducing to them the following technical section, written in the language by which geologists talk to one another. Translated it reads as follows:

The Dominguez Range of folded strata was being made in the latter half of Pleistocene time. The rising range created a barrier between the sea and land, against which marine formations were deposited on the seaward side (the Centinella formations) and continental formations, such as the "blue freshwater" clays (the "La Brea Formation") and "playa" stream and "outwash" deposits on the land or interior side.

Section of Recent and Pleistocene Formations exposed in the Outfall Sewer Excavations through La Cienega Basin and La Ballona Pass, Los Angeles, Nos. 1-10a inclusive are abbreviations of the original section by Dr. A. J. Tieje[1]. Nos. 12-14 are additions by the writer.

14.	Sandy soil, largely Recent outwash from adjacent regions	1-5
13.	Sandy loess-like eoliates	2-8
	(unconformity)	
12.	Finely-bedded, small-particled micaceous sand and loam, with beds of peat interlayered, fresh-water shells and petrified, stoney, silicified human bones at depths of 20 to 25 feet. Probably fresh-water lacustral deposits of latest Pleistocene or Recent age (in question)	20
	(unconformity)	
11.	Centinella gravels[2] with warmer-water, marine fossils (Tieje). Exposed on ocean side of Dominguez Range (R. T. H.).	
10.	Boulders, unconsolidated river materials	1-20
	(unconformity)	
9.	Bluish fresh-water clays La Brea Stage[3] (5) alternating with micaceous sands and river gravels. Blue clay No. 2 with sloth remains	300
8.	Unfossiliferous sands	150

[1]Bulletin A. A. Pet. Geologists, p. 505.

[2]On page 510 Tieje states that 70 feet of strata largely marine sands and gravel lie stratigraphically above the youngest blue clays (No 9) of Trench 10. These he called the "Centinella Gravels."

7.	Palos Verdes sands[3] fossiliferous, warmer climate	50
6.	Unfossiliferous sands	104
	(faunal unconformity)	
5.	San Pedro ("clayey sands of the San Pedro") stage[4]	100
	(faunal unconformity)	
4.	Grits. Fossiliferous and laterally variant to gravels	1-4
3.	Sands. Unfossiliferous (?) of beach type.	0-25
2.	Sands. Fossiliferous, warmer-water fauna (unconformity[5])	0-25
1.	Upper Pliocene sands. Markedly clayey, fossiliferous, cold water fauna	223

FLEXURED FOLDS OF THE VENTURA RANGES

On previous pages I have briefly defined the Ventura Ranges, which consist of a belt of several parallel elongated narrow ribbons of highlands and alternating valleys adjusted to anticlinal and synclinal folds and accompanied by some faults of similar extent and trend. That such narrow folds should persist as they do through great distances is a remarkable feature, but the fact that several parallel folds should occur in a curved, belt-like arrangement is still more unusual. This occurrence is like that of the strands of beads in a lady's collar that have been collectively and horizontally pushed into curvilinear arrangement.

Furthermore, it is possible that the trend of the southernmost of the ranges after crossing the Los Angeles and San Gabriel rivers, may again bend by

[3]Tieje identifies this horizon with the "La Brea Stage."
[4]The upper San Pedro of Arnold.
[5]This unconformity was "inferred."

the way of the Montebello, Puente and San Jose Hills, first east and then northeast again, which make the eastern end of a great, sinuous, double-curve of trends between in the longitudes of Ventura and Claremont. This, however, is all vaguely conjectural.

There are also sinuous, east-west lineaments in the summit of the San Bernardino Plateau which sharply bend or drag to the southward at the eastern side of that feature, having been there cut across by the north-south extending Whitewater Fault.

Excellent cross-sections of the successive faults and folds of the Ventura and western Los Angeles regions are given by Kew in a Bulletin No. 753 of the United States Geological Survey.

PART FIVE

THEORIES OF THE CAUSES OF FAULTING

Why did all of these great earth features of which I write, exist—the faults, their rectilinearity and directions of trends, the great flextures, the successions of belts and other striking characteristics? What forces made them; Why, when and how? Truly these are large questions to try to answer in a limited pamphlet; in fact, hard to answer at all.

All movements of the earth crust are included by geologists under the formidable word "diastrophism." Let us briefly state what is known of diastrophism and its causes.

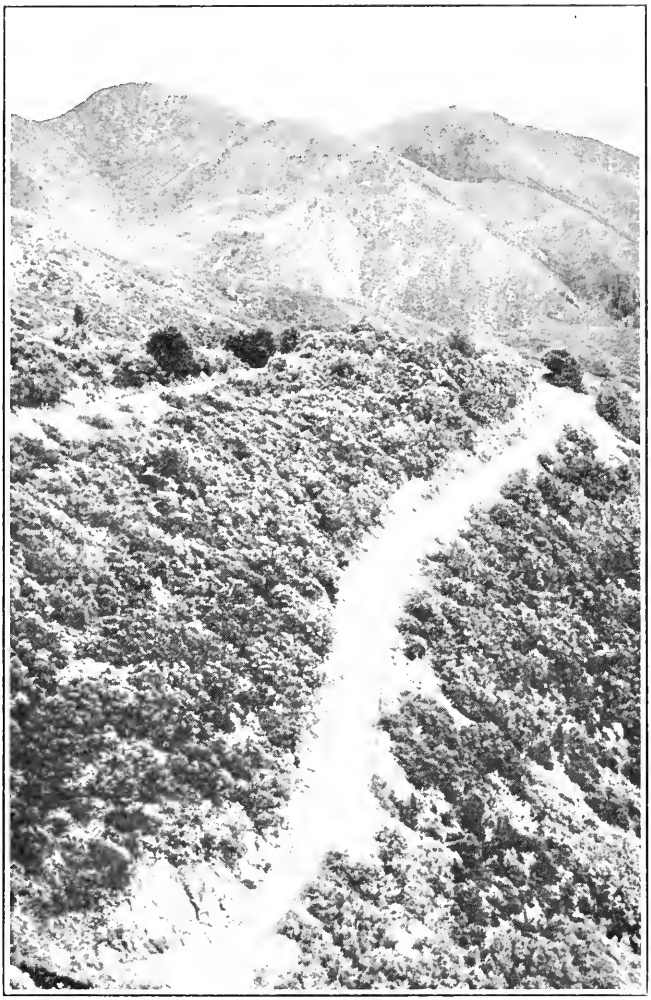
THE CONTRACTIONAL THEORY

We will still find it stated in most text books that the greater inequalities of the surface were produced by the contraction of the earth's center or interior by cooling. This is known as the contractional theory. It has so far failed to explain the great fault displacements of Southern California and the Pacific Coast in general, so different from the folded Appalachian structures of the Atlantic side and of the Alps Region, whose folded conditions gave rise to the contractional theory.

THE THEORY OF ISOSTASY

We find on consulting the leading present-day authorities—mostly men unknown to the masses whose conclusions have not as yet appeared in text books—that the contractional theory has been discarded, and in its place another has been substituted which might be called the equilibrium theory, but which is actually called "isostasy." Isostasy, then, deals with flotational movements of adjacent segments of the outer layers of the earth's crust—the zone of fracture—above a lower, heavier, more plastic zone of flowage. The up and down movements are due to the subtraction and addition of load from certain segments of the crust, causing them to rise or sink in the plastic substratum. Movements or change of load from one part of the earth's surface to another produce isostatic equilibrium. Such movements are the ultimate accomplishments of the work of volcanism, which transfers load from the sub-surface to the surface; of drifting clouds which transfer moisture from the ocean to the land where it makes rainfall and glacial snow deposits; and of the transportative work of the streams and wind which transfer load from the highlands to the ocean border.

The doctrine of isostasy conceives that the great interior of the earth is so dense and rigid that further shrinkage there is impossible and that the movement must be within the outer, or rock girdle. This rock girdle, or so-called crust of the earth, is subdividable into a cooler, lighter, upper zone of fracture and a lower, hotter, heavier, plastic zone, or zone of flowage. The rocks of the fracture zone are less dense than



EDGES OF FAULT BLOCKS GROOVED BY ANCIENT GLACIERS

those of the zone of flowage and the former are supposed to glide, flow, float, or sink above and within the latter, just as a log of wood or a cake of ice may move about in water. The depth of the zone of fracture, which is also the depth within which faulting movements may occur, may probably reach twenty miles.

The highlands rise as their surfaces are relieved of load by erosion, and as the eroded materials are transported to the margins of the sea by the combined work of sun, wind, clouds, rain and rivers. Correspondingly the sea margins sink as the loads are deposited upon them.

The sun lifts vast loads of water from the surfaces of the ocean and land—more from the former than from the latter—and the wind transports it as clouds to be deposited in another place as rain and snow load. If you wish to see the work of isostasy, watch the sources, distribution and destinations of the dust of the air, the clouds of the sky and the flood-time sediments of any of our California rivers.

The latest work of the great geophysicists of the world—Wegener of Austria, Daly at Harvard, Hayford and Bowie at Washington, Joy in England—and others—has shown that these great isostatic processes, such as up-and-down and horizontal or lateral drifting movements, have played as great if not a greater part in the deformation of the surface of the earth as has contractional compression. While compressional movements have participated in the geologic structure of California, the drifting and up-and-down floating movements have also been most important factors, as testified by the various fault blocks of California which we have described. In fact, lateral compression

may, in instances, be the accompaniment of stresses between horizontally drifting segments.

KINDS OF CRUSTAL MOVEMENTS

Briefly the different kinds of crustal movements may be placed in three groups:

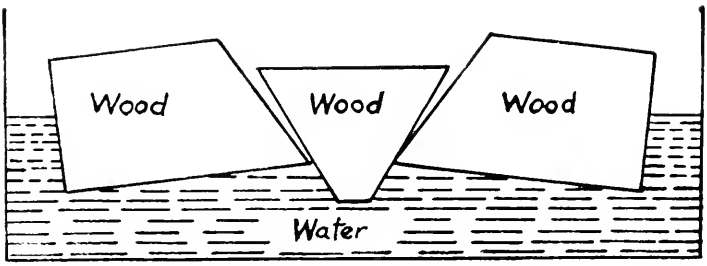
1. Up and down (flotational) movements produced by transfers of load from one place to another through processes of erosion and transportation.
2. Horizontal-drifting movements of segments of the earth's crust produced by stresses of revolution, sub-crustal undertow and other unknown causes.
3. Compressional movements of the kinds previously mentioned.

Faulting, folding and volcanism are more or less associated with the above mentioned kinds of movements.

Thus these three great kinds of directional movement of segments—compressional, drifting and flotational—have each been factors in producing our faults and folds and the resultant highland and lowland physiography. Of the three, the up and down flotation has produced the most conspicuous effects upon our physiography, as seen in the great master rifts and fault-block highlands and valleys. Each and all, in my opinion, are superb illustrations of the work of isostasy and of the near truthfulness of the theories of our modern school of physiographers and geophysicists.

THE UP AND DOWN MOVEMENTS

Up and down movements take place slowly throughout long intervals of time and have produced the chief aspects of our magnificent physiography, including



Floating wood blocks which illustrate the up-and-down isostatic movements of fault blocks. (Tabor)

the alternations of picturesque highlands and productive valley plains and various other apparent peculiarities of the landscape that give individuality to Southern California.

The extent of the vertical movement of the great fault blocks, as I have shown on previous pages, often aggregates 20,000 feet or more. Such conditions may be seen along the borders of the San Gabriel, San Bernardino and San Jacinto Ranges. These blocks are clear, large-scale demonstrations of the theory of isostatic adjustment.

To fully appreciate the vertical movements which they have undergone, we must remember several important facts. The first of these is that the granitic rocks which compose any one of these uplifted fault blocks, such as the San Gorgonio Ridge of the San Bernardino Range, which at present stands over two miles above sea level, were probably made at depths of twenty miles or more beneath the surface of the earth; also that these granites were once covered by an equal thickness, or overburden, of rock ma-

terial which wore away as the block rose to its present position. Thus the block, as we now see it must represent a total upward movement of at least forty-two miles.

THE HORIZONTAL MOVEMENTS

It has been alleged that horizontal, or drifting movements, have taken place on a large scale throughout various parts of the earth, as has been set forth in Wegener's recent and much discussed book on "The Origin of Continents and Oceans." Great, drifting movements of this kind have taken place in California in times past, and may probably be slowly continuing at present, but certainly not at the great rate which prophets of earthquake disaster would have us believe.

The causes of these drifting movements are not positively known, but it was long ago suggested[1] (before the theory of isostasy was advanced) that they might be the result of a lag in the movements of some of the larger continents in comparison to that of the smaller ones.

RENEWAL OF MOVEMENT ALONG OLD FAULT LINES

There is much evidence that, while fault lines may have originated and had their maximum movement in some one particular epoch, renewal or repetition of movements along the line may have taken place in one or several later epochs, or even have continued in lessening degree into the present time. Noble has shown some fine examples of such renewals of movement along fault lines of great antiquity in the region of

[1]Emerson, B. K. The Tetrahedral Earth and Zone of the Inter-continental Seas. Proc. Geological Society of America (Vol. 11, 1900).

the Grand Canyon of the Colorado. Most of the master rifts of Southern California which were all made in the Pleistocene or preceding epochs, show some evidences of recent movement.

Some of the master rift-lines of the Pleistocene may have been inherited from older and earlier fault lines. In fact, there is some suggestion that the path of the transverse structures described represented a renewal of movement along the lines of an old east-west embayment which existed in Paleozoic times, as shown by Schuchert in his paleogeographic maps.

CAUSES OF THE DIRECTION OF TRENDS

A most striking feature of the faulted structures is their occurrence in parallel and belted groups of various directions. The inquiry naturally arises as to how these conditions have been brought about.

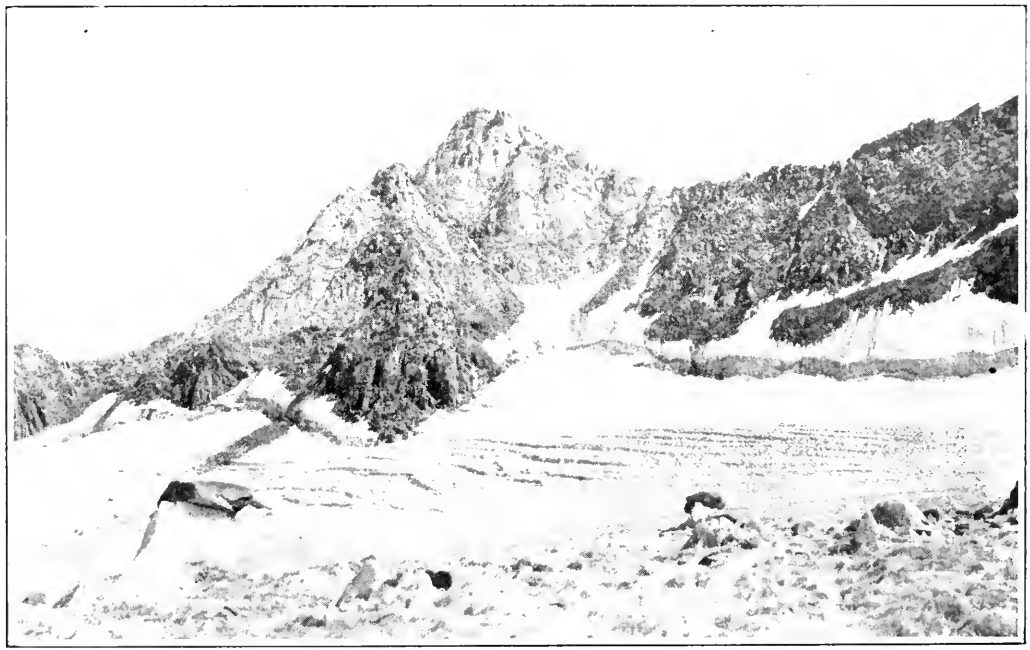
Inasmuch as the load-relieving quantities of sediments derived from the continents are laid down as loads in the margins of the sea, the sinking of the margin and the corresponding risings of the adjacent land are usually parallel to sea coasts. From these facts it may be deduced that the directions of most of the master displacements of faulting or folding which accompanied such stresses likewise paralleled to the shore at the time of their creation. But all of the various belts of master faults in Southern California do not now trend in directions parallel to the present-day directions of the coast. Neither are they parallel to the normal north-southerly or longitudinal direction of the earth's axis which direction the coast tends to follow. Certain factors to be later discussed are responsible for this notable deviation in

trend, and as far as I am aware, they offer the one possible explanation.

The combined phenomena of flexured trends and transverse structure are associated with the drifting conditions previously described, and constitute a great buckle in the normal, north-southerly directions of the continental trends whereby the regions to the north and south of the Great Transverse Belt have moved west and east to one another respectively.

Studies of the structure pattern have convinced me that the bending of the great belts of parallel structures of the Ventura Ranges which at one time may have had rectilinear directions, has been accomplished by great, horizontal, northwesterly-southeasterly pulls in the earth's crusts, and not by northerly stresses as asserted by Willis. Such movements may have resulted in the relative driftings to the northwest and southeast respectively of the regions to the north and south of the San Andreas Rift.

Such movements have produced the abnormal, north 65° west directions of the Valyermo section of the San Andreas-Puente Belt and the faulting and the flexuring of the Ventura Ranges. In some instances, as in parts of Ventura County, the strains resulting from the stresses of such bends have become breaks with the resulting confusion and displacements of the structure and the lineaments of the physiography. In fact the torsional horizontal stresses and strain were so great at one place that the curvature of the flexured ranges collapsed into buckling as seen in both the instance of the San Cayetano overthrust and in the disturbed structural conditions adjacent to Hopper and



EAST FRONT OF SIERRA NEVADA
Some fault scarps rise to glacial heights (Kindness Wm. Mulholland)

Piru Canyons. These are both shown on Kew's map of that region.

CAUSES OF THE FOLDING

Aside from the larger questions concerning the causes of earth movements in general, whether contractional or isostatic, as briefly mentioned in the next chapter, there are two theories as to the causes of the elongated folds. One of these holds that they are made by lateral compressions which resulted from loadings of sediments along the margins of the sea. The other holds that the folds are incidents of the flotational and drifting movements which produced the master faults.

In the instance of the parallel ranges of the Ventura Group, Kew holds that they were made by lateral compression acting from the direction of the sea. According to Willis, diagonal pressure on the fault planes of the San Andreas Rift from the southwest tends to move the block on the west to the northwest and the blocks on the east to the southeast. He also states that the pressure from the southwest is a "growing pressure." I have disproved this latter theory in the introductory part of the work.

There is some evidence on the side of those who hold that these folds are the results of compressions between the fault lines. The folds of the Badlands Range of Pliocene strata are clearly the result of compression within a fault block between the San Jacinto and San Andreas Rifts. On the other hand, cross-sections of the Downey (Los Angeles) Valley Plain suggest that faulting followed or accompanied the folding. A synclinal trough between the Domin-

guez and Puente Ranges shows a fold with secondary faulting on its north side adjacent to the Puente Range.

CAUSES OF THE CHANGES OF TRENDS

These deflections of the various trends from a normal, north-south direction may reflect stages in the continental history when the trends swung partially around the circle of directions, first from north-south to northwest-southeast; then from northwest-southeast to northeast-southwest; from thence to east-west; and from thence back through the arc to northwest-southeast again. All of which conjectures are theoretical.

The theory that the various directional belts may be of different ages, is a striking one for which we, at present, see no explanation, except that they may reflect changes in the position of the earth relative to the direction of the polar axis. While that vague form of history known as "myth," which came down by word of mouth to the ancient Egyptians, Jews, Hindus and Chinese, supports it, geologists are divided as to whether such changes have ever taken place and some astronomers repudiate the idea entirely. Wegener, however, approves the theory[1].

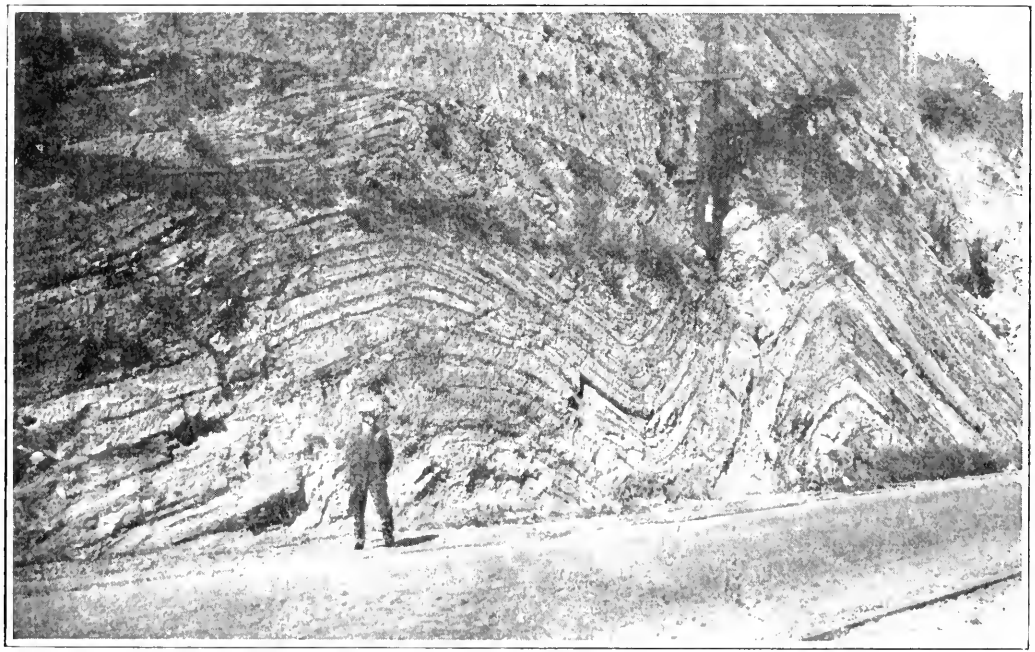
If such changes have taken place, it would not be diffcult to conceive that they had resulted from the isostatic effects of adding to or subtracting from local crustal loads portions of the crust by the accumulation or melting of the gigantic ice sheets during the glacial stages of the Pleistocene epoch.

[1]Origin of Continents and Oceans p. 128.

RECURRENCES OF TRENDS

There are also suggestions of the recurrences of the same direction of trend in different epochs. The northwesterly trends of the Coast Ranges and Catalina groups, probably made at the close of the Miocene, were apparently next replaced by east-west and torsional directions in the late Pliocene and earliest Pleistocene epochs, though still later they may have repeated themselves in the Pleistocene and Recent epochs.

The fact that the various trends cross one another at various places in Southern California has already been set forth. At first glance the student might conclude that this crossing of the master faults and belts of faults is due to complemental faulting. If such be the case in some instances, I do not know of them. On the other hand the proofs of the existence of fault belt groups of different ages and of the fact that they have crossed one another are too positive to be ignored and I believe the explanation for this crossing will be found in the conditions just described.



FOLDED STRATA BETWEEN FAULT LINES
Avenue 64, near Church of the Angels, Los Angeles

PART SIX

GEOLOGIC HISTORY
OUTSTANDING EPOCHS OF GEOLOGIC HISTORY IN SOUTHERN CALIFORNIA

For the purposes of this paper the geologic time column in California may be divided into two grand divisions. The oldest of these includes all the geologic periods up to the close of the Jurassic, at which time the great intrusion of granitic magmas of the Sierra Nevada took place. This, one might term, the time of the Basement Complex. The second of the grand divisions includes all the periods and epochs since the close of the Jurassic, and may be termed the time of the Superjacent Series. The latter includes the events of the Cretaceous, Tertiary and Quaternary Periods. Only the occurrences of the two last periods of the Superjacent Series—the Tertiary and Quaternary periods need concern us now.

Events during the time of the formation of the Basement Complex in California, relative to those of the Superjacent Series, are comparable to the relationships between the Proterozoic and Paleozic eras in eastern North America. Both of these earlier times were prologues to the succeeding and less obscure ones. The study of the earlier of these subdivisions of geologic times includes a consideration of every thing that has made the study of geology a dead

and an uninteresting science to many people. Consideration of the events of the later ones are replete with interest pertaining to human environment such as can hardly otherwise be found. In California it is the story of a live world at work, not of a dead one.

It is only with the latest portion of the geologic time scale in Southern California that we are particularly interested. This includes the latter days of the Pliocene, Pleistocene and Recent epochs, those yesterdays of geologic time, which in northern regions, especially in Europe, include the Glacial epochs and are known as the Age of Man. In fact the geologic history of Southern California practically begins where that of other regions leaves off. Nor will it be an exaggeration to state that most of the great, geologic effects around us, as we see them expressed in the physiograpic environment of Southern California are the records of events that took place in the Pleistocene epoch.

PERIODICITY OF EARTH MOVEMENTS

Geologic history teaches us that there have been great cycles of increased earth-making movement alternating with epochs of quiescence during the long course of geologic time, and that the effects of such movement constituted the great barriers which divide the true geologic periods. Although lasting through vast stretches of time, which are incomprehensible in terms of years to the human mind, each movement had a life-cycle of birth, growth and decline of activity. Records and vestiges of these movements are now found as great unconformities and mountain systems of different ages throughout the world.

Among the cycles of movement of this kind were those that produced the Appalachian mountains at the

close of the Paleozoic; the Rocky Mountains at the close of the Mesozoic; the Great Basin faulting during and at the close of the Eocene; the Sierra Nevada and Coast Ranges at the close of the Miocene; and several movements during the Pleistocene or Ice Age which are reflected in the various glacial and interglacial epochs and expressed by the various directional fault systems of Southern California.

The climaxes of epochs of earth movement in Southern California took place at the close of the Fernando (late Pliocene); during Middle Miocene (Puente); at the close of the Tejon and Martinez epochs of the Tertiary; and at the close of the Cretaceous and Triassic Periods.[1]

From the studies of the belted groups of faulted structures herein given it seems that there might have also been alternating epochs of earth movements in Southern California since the great revolution during the close of the Pliocene and in the Pleistocene, characterized by times of intense fault-making stresses intermittent with times when the stresses were less intensive, and that the fault movements of each interval of activity followed characteristic lines of direction, different from those of the others; say north-south in one epoch, northeasterly in another, east-westerly in still another and northwesterly at one or more times.

Do the small present-day movements in California mark the beginnings or close of one of the vast cycles? That is a most important question, because of its bearings on seismology.

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[1]Well summarized by English in Bulletin 768 of the U. S. Geological Survey, Washington, 1926

SOUTHERN CALIFORNIA BEFORE THE GLACIAL PERIOD

The geographic conditions in Southern California during the Pliocene prior to the mountain-making revolution near its close, which initiated the Pleistocene epoch are not satisfactorily known, but were approximately somewhat as follows:

A background of the older lands existed, consisting of the Basin Range Region, some Coast Ranges, a Sierra Nevada highland less conspicuous than the one of today and possibly a diversified lowland area, fragments of which now occur as the summit lands of the San Bernardino, San Gabriel and Peninsula Highlands. The Gulf of California Depression extended even farther northward than today into the present site of San Gorgonio Pass.

The land area mentioned constituted a nearer sea-level country than now, with its rivers and fresh-water lakes and low hills and ranges. Its shore line did not extend seaward as far as it does today. The site of Los Angeles was then under water.

THE PLIOCENE PENEPLAIN

This hypothetical lowland, developed at or near the close of the Pliocene, constituted the stage-setting for all of the great events which were to take place in Southern California during the succeeding Pleistocene and Recent Epochs, when it was sliced into fault-block segments by the great rifts we have described, and its fragments elevated or depressed into the master highlands and valleys, practically as we see them today. By this means the physiographic environment upon which all other conditions were to depend—climatic, scenic and cultural—was developed.

These latter-day events were all parts and reflections of the greater isostatic history of the Pacific Ocean Basin—a history as yet unwritten and which will reveal much when done.

SOUTHERN CALIFORNIA DURING THE GLACIAL EPOCHS

The four or more great ice loads which in Glacial times covered much of the northern portions of our continent and of Eurasia are not known to have extended as far south as California, although mountain-top glaciation was much more in evidence then than now. The abundance of ill-sorted, fragmental rocks distributed over the foothills and margins of the valley plains by outwash from the highlands has led many to associate these phenomena with wide-extending glacial deposits, but they are mistaken. Nevertheless great geologic events were taking place in Southern California during the glacial epochs, as will be shown.

CAUSES OF EARTH MOVEMENTS IN THE GLACIAL EPOCHS

The fact is that almost incalculable weights and quantities of water were gathered from the surface of the ocean, transported and redeposited as loads of snow and ice upon restricted, continental areas during the Glacial Epochs, and that they must have constituted great earth loads of vast isostatic potentiality. Billions upon billions of tons of water were transferred from the ocean to the lands thereby lowering the surface of the latter and lightening the load above the bottoms of the former. These loads, unless the theory of isostasy fails us, must have caused great sinkings of those portions of the crust immediately beneath them

and corresponding uprisings of the surrounding and outlying regions where the loads did not exist. These movements were accompanied by foldings and faultings of the kinds which we have described.

Although situated southwest of the margins of the former ice sheets that weighed down the crust of the northern regions, one finds here in California the records of certain other synchronous events which cause us to believe, if the theory of isostasy is true, that the presence of these inexpressibly heavy ice loads of distant regions above the plastic sub-crust and the removal of water load from above the oceans, must have had wide effects upon the outlying areas, including Southern California.

It is here then, in Southern California that we should find the events of the great Glacial Epochs recorded in terms of profound crustal movements of the kinds which we have already described, and which are reflected in the present-day fault lines, highlands and valleys. These effects are so overwhelmingly conspicuous in Southern California that we wonder that they have not attracted the attention of geologists rather than many other and less important subjects.

The more we grasp and absorb the great principles of isostasy, the more apparent does it become that vast equilibristic efforts must have influenced the regions bordering the ice-sheets of the glacial periods. This effect being the result of the deposition and later melting of the tremendous ice loads over large, but restricted portions of the yieldable earth's crust. Probably each of these four or more ice loads initiated crustal movements of far-reaching extent, and it will probably be ascertained in the future that the great

fault systems of Pleistocene time are related to them. Likewise it is probable that each cycle of loading and unloading of ice may have produced a corresponding Hyrcenian cycle of earth movement, and that each of these cycles may be related to one of the directional groups of faulting herein described.

It was during the great Glacial Epochs—close of Pliocene Time and the beginning of the Pleistocene—that the last, great mountain-making movements of Southern California took place. Nearly every highland and lowland which we now see around us was largely made or added to during these epochs. Even our Dominguez Range, which we speak of as "recent," was made in the last half of the Pleistocene. In terms of human chronology it is hundreds of thousands of years old. Most of the great master fault lines and fault scarps, and all of the master highlands and rift valleys of Southern California were either made or rejuvenated in Pleistocene time.

Beyond doubt we are now living in an interglacial epoch of decreasing structural activity, due to the removal by melting of the ice of the last great glacial load. Furthermore activity will continue to decline for fifty thousand years or more until an up-turn of the climatic curve sets in and a new glacial period begins.

It is the general geologic opinion that we are living in the early portion of an interglacial epoch during which the northern ice loads are melting and the earth stresses and strains are lessening. From this fact and others associated with the history of the glacial eras we maintain that Southern California is passing through a period of decline in seismic activity.

Probably this decline is taking place so slowly that it will hardly be appreciable to our day and generation, but the thought is far more assuring than the imaginary, alarming and unfounded conjectures of disaster.

INTERESTING EVENTS IN THIS VICINITY DURING THE GLACIAL EPOCHS

It was during the Pleistocene that most of the great belted trends, highlands, valleys, sea coasts, terraces, islands and other features of the topography that I have described, and that have given to Southern California its charm and lure of today, were made; that the lands on the opposite sides of the San Andreas Rift are supposed to have had their greatest horizontal drifting past each other; that the high and lowland blocks chiefly moved up and down; that our older rivers were dismembered or diverted; that our sea coast line migrated back and forth; that the beautiful elevated terraces were engraved upon the borders of our islands, coasts and inland mountains; and that the great transverse buckling of the trends took place.

It was in Pleistocene time that much of the materials of the stratified rocks were deposited; that the strata of our ranges of the Dominguez, Ventura and Puente types were folded into their oil-containing arches, and that the alternating valleys were also made and veneered with their wealth-yielding soil. Erosions of the rising highlands, and loadings of the sinking coasts and valleys by sediments were also active.

Also during this epoch the "Atlantis"-like subsidence of our continental margin took place; the western and southern continuations of the Coast Ranges may have disappeared beneath the Pacific's waters; the

east-west trending ranges of the Channel Archapelago arose across the path of the older northwest ranges mentioned; while a former valley plain of the land subsided to make the Santa Barbara Channel.

In fact it was during the earliest of the Pleistocene epochs that the great Transverse structures arose across the continent and separated Northern and Southern California, like the "earth was divided" in Peleg's day.

Climate is the servant of geology, and temperatures and precipitation in Southern California during the Pleistocene epoch likewise reflected the presence or absence of the northern ice sheets. Life, too, then responded to the great structural and climatic changes, as is witnessed by the presence and extinction of peculiar forms such as have been found at La Brea and other places, for here camels, elephants, horses, sabre toothed tigers, lions and peacocks flourished.

It is even probable that in the last days of this Pleistocene epoch early man may have appeared upon the scene in California. The writer believes that the human remains of La Cienega Basin at Los Angeles are of the latest days of this epoch.

And, finally, it was during these epochs that the great fault and earthquake-producing movements comparable to those now active on the west side of the Pacific Basin, here attained their maximum and began to diminish before the present time of comparative quiet and moderate seismicity.

The collective details of this story of Southern California in Pleistocene time is one of the most fascinating of all the annals of geologic history, and one which overshadows all others in relation to this particular region.

RELATIONS OF THE PHYSIOGRAPHY TO FAULTING AND SEISMICITY

Inasmuch as the relief of the master highlands and lowlands is largely the result of the master faulting, their histories, together with the subordinate conditions of seismicity, must be somewhat inter-related. The fact that the relief features have moved up and down or laterally by successive impulses in harmony with the fault movements is well shown in the instances of the San Bernardino Plateau, the body of which is a segment of a former, diversified, lowland peneplain which has been elevated by several uplift stages to its present position. Correspondingly there have been developed on its sides a broad series of step-down faults and bench-like terraces and its summit area shows evidence of several, interrupted erosion cycles. These conditions all serve as records of Pleistocene and perhaps earlier history. The youngest highlands, on the other hand, of which the Dominguez Range is an example, are of low altitude and exhibit but few evidences of the marginal phenomena above mentioned.

Likewise we may deduce the fact that in Southern California the structural highlands of greatest altitudes are relatively the older ones and that those of lower altitudes are the younger in age. These conditions are quite different from those usually observed in other and older regions of the United States, where the lower mountains are the older, having been worn down by long erosion, while the higher mountains are the newer.

[1]See "Geology of the San Bernardino Mountains" by Francis Vaughan, Univ. Cal., Geol. Bull., 1922.

It is a further anomoly that the older portions of our rivers, as seen in the areas of our valley plains, are apparently the least indented ("canyoned"), inasmuch as their traces are constantly being filled and abandoned by processes of distributive aggradation.

So far as I am aware, no geologist has hitherto attempted to point out the distinction between the minor interior faults and the master ones, the latter of which outline and block out the major features of the topography; or to classify the faults into various belts or groups; or to suggest the possibility that there is an age sequence to these groups as I have attempted to do in this paper.

Geologists now seem in agreement that most of the master faulting of Southern California dates back through the Pleistocene epoch, and that it has been more or less continuous through that epoch into the Recent. In some sections the age of the faults may extend back into the Eocene Tertiary.

GEOLOGIC HISTORY OF THE FAULT SYSTEMS

Wrong interpretations might be made of the fault phenomena of Southern California if one is too prone to ascribe to present-day activities many events which have actually happened in the past; to fail in distinguishing between events of Pleistocene and Recent times in the geologic history; or to labor under the mistaken idea that faulting and seimicity are as actively operative today as they were in the recent past.

Until quite recently there seems to have been no clearly set forth opinions concerning the ages of the fault systems. Only a hazy idea existed that they were an unclassifiable and indefinite mesh-work of fractures of possibly contemporaneous age. And

no other view was possible in the absence of appropriate data. Recently, however, English[1] and Noble[2] have presented some valuable data on the subject.

Although my interpretations are confessedly imperfect, it seems to me that at least some of the fault-belts herein described may be the records of distinctly separate, structural unities of a sequence of movements of different epochs. There are many reasons for believing that such a sequence exists and will ultimately be more clearly defined. Although the classification presented has been studied by the writer for many years, he does not by any means consider his conclusions as final.

Many of the great master, scarp-making faults are of Pleistocene age, but movements along them may have been revivals of those initiated in remotely previous epochs and may be continuing in some instances into the present time.

Faulting, in some instances, may have originated along lines of earth weakness or along sea borders which existed in remote geologic times, although the immediate expressions as now visible are the effects of revived movements of later times.

Besides the light thrown upon the age of the faulting by aid of physiography, there are two other lines of evidence whereby the ages of fault systems may be determined. One of these is by ascertaining the age of the latest strata cut through by them. The other is evidence afforded by their intersections with one another.

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[1]Bull. 768, U. S. Geological Survey, 192.
[2]Carnegie Institution Bull., 1926.

FOLDED STRATA BETWEEN FAULTS, DARK CANYON BOULEVARD, LOS ANGELES

TESTIMONY OF THE STRATA

There are many instances of age sequence in the fault groups which have been determined by stratigraphic and paleontologic details.

Merriam and others have shown that the earlier filled-in sediments between the Basin Ranges contain Miocene vertebrate fossils; whence he deduced the fact that the faults which made these valleys were of Miocene or earlier periods.

The Colorado Desert end of the great Gulf of California Depression is partially filled with late Miocene or Pliocene Marine deposits, as determined by Kew. Therefore, we may also conclude that the faulting which produced that depression is of Miocene or earlier age. It is not an unreasonable hypothesis to consider it of the same age as the faulting of the Great Basin Region.

The marine Eocene and Miocene strata near Valyermo are downthrown several thousand feet into contact with the granites of the Basement Complex, as has been mapped by Noble, thereby testifying to the past Miocene age of that portion of the rift, and of the adjacent San Gabriel block of highlands. W. H. English thinks the block is of Pleistocene age, and I agree with him.

Positive proof of the Pleistocene age of the San Jacinto fault is the fact that it cuts definitely across fossil-bearing Pliocene strata of the Badlands Range. Strata of Eocene, Miocene and Pliocene ages are found in the trough or graben of the Elsinore rift, thereby proving the Pleistocene age of that rift. Slivers of Miocene and Pliocene sedimentaries are found along the master rifts of the San Gabriel High-

land (Noble and Kew), which prove the Pleistocene ages of some of these rifts. The first Northwest group of rifts of the submerged portion of California are probably post-Miocene because in Miocene time the islands were connected with the land, and the development of the faults in later times is the best explanation for the separation.

AGES OF THE NORTH-SOUTH GROUPS OF STRUCTURES

It has just been shown that the North-South groups of structures of the Great Basin Region were initiated as far back as the early Miocene or Eocene epochs. It is probable that the great rift or rifts which more or less theoretically mark the east side of the Peninsula Highland and the trends of the northern end of the Colorado Depression are of similar age. Furthermore, the structures of the two regions may have been at one time more or less continuous before the great fault line of the East-West and Northwest systems crossed their paths.

RELATIVE AGE OF THE NORTHEAST TRENDS

The northeast-trending faults of the San Gabriel and San Jacinto highland regions are apparently cut directly across by the east-west extending faults of the Transverse Belt and by the north and west striking faults of the San Andreas-Puente Belt. They may be of Pliocene or at latest, early Pleistocene age. This assertion is a tentative one, however, owing to the indefiniteness and incompleteness of the data which now is possessed concerning these northeasterly extending structures. Movement has certainly taken place along the Garlock fault since Pliocene time, as is explained upon another page.

AGE OF THE TRANSVERSE FAULTS

The east-west extending faults of the Transverse system are assumed to be newer than the first Northwesterly and Northeasterly Groups, which are cut out by them. As a generalization it may be said that the north-south trends of California—those of the Basin and Coast Ranges—have been cut directly across and out by the great rifts of the east-west group. From the fact that the east-west rifts are cut out by the north 65° west-extending San Andreas-Puente Belt and the north 45° west San Jacinto fault we presume that they are older than the second Northwest groups.

The older northwesterly-extending folds of Miocene strata seen on the east end of the Santa Monica Range, were cut across by a revival of movement along the east-west-extending Santa Monica fault in early Pleistocene time, and the folds in turn are cut across by the later northwest faults.

There is a suggestion that some of the east-west rifts of the San Gorgonio Pass were initiated before the deposition of the Badlands strata which contain fossils of Pleistocene and Recent time. Some of these faults outlined the north end of the Peninsula Ranges and the Pass itself. It is evident that they date back to Miocene time or before, although later renewals of movement along them have taken place locally.

RELATIVE AGES OF THE NORTHWEST GROUPS

The ages of the Northwest-trending Structures range from Pliocene to Recent. On a previous page it has been confessed that this provisional classification is merely a makeshift one. The trends may have prevailed both before and after those of the east-west directions and therefore are of, at least, two ages. The

oldest of these were probably associated with the making of the Coast Ranges proper and the Catalina trends of late Miocene or Pliocene time. The later group of the San Andreas type were mostly created in Pleistocene time.

It is suspected that some of the structures of the older category were prominent in Southern California before their conspicuity was diminished by later events, as, perhaps, in the instances of the older folds which appear with the Santa Monica, tilted fault-blocks. Likewise, some of the faults which are apparently of Pleistocene age, may be revivals of movements along pre-existing faults.

Late rifts of the Northwest groups cut across rifts of all the other groups and bend into the trends of the San Andreas-Puente group. Therefore, it is concluded that the latest faulting in California was of this northwest direction.

EVIDENCE OF PLEISTOCENE AGE IN SOME OF THE MASTER FAULTS

It is now evident that while the most conspicuous of the master faults mentioned may have originated in more remote epochs they may have had great, if not their greatest, displacements in Pleistocene time.

Several of these are known to cut across or to deform the Pliocene strata and therefore are of post-Pliocene or Pleistocene ages. Some of those that cut Pliocene strata in the hills are covered by more recent strata in the valley plains. Hence, we cannot escape the deduction that such faults were largely made in the Pleistocene epochs and before the Recent. Among the master rifts, along which there is proof that there was great movement in the Pleistocene

epoch may be mentioned, the San Gabriel, Sierra Madre, Verdugo, Puente, Elsinore, San Jacinto, San Andreas, Mill Creek, Newberry, Cadiz and Garlock faults. In fact I believe that there was movement along most of the master faults of Southern California in Pleistocene time.

That the master faulting which chiefly produced the present day aspects of Southern California took place prior to the Recent epoch is testified by the defacing erosions which the escarpments have suffered since their origin and which must have required considerable lengths of time for their accomplishment. This is also testified by the fact that the extensions of the fault lines across the valley plains are buried and concealed beneath the sediments of post-Pleistocene age.

The outstanding fact of the geological history of Southern California is that the great earth movements whose features outline our present day physiography, took place in various epochs of the Pleistocene. This was the time of the Great Glacial Epochs in North America and Europe; of the "forgotten age" of mankind, whose myths which have been handed down to us, tell of the prehistoric "earth dividings," "polar changes," "disappearing continents" and human dispersals—all of which tradition affirms and which science may some day explain.

The following specific instances of movement along these fault lines in the Pleistocene Age may be mentioned:

1. The marine Pliocene strata of the Colorado Depression which originally were deposited below sea level have been uplifted 1,000 or more feet by a movement along the easterly Mill Creek fault at its north end,

as is shown by occurrences of these formations in the Mecca Hills and by later movements of 3,000 feet along north-south rifts to the west and as seen in the north bench of the San Gorgonio Pass. The two movements which brought about these conditions were of post-Pliocene (Pleistocene) Age.

2. The master faults of the later northwest and east-west systems cut across strata of Pliocene age in many places, as, for instance, in the La Canada, Los Angeles, Ventura and Puente districts and where the San Jacinto Fault cuts across the vertebrate fossil-bearing Badlands strata.

3. The Ventura Ranges include Pliocene strata in their up-turnings, hence some of the folds and faults are, in part, of post-Pliocene or Pleistocene Age.

4. The San Andreas Rift which, according to Noble, may have originated as far back in time as the Mesozoic cuts across Miocene and Pliocene strata along the San Bernardino escarpment and in San Gorgonio Pass. I estimate that the San Bernardino Plateau, as a whole, has been elevated from 3,000 to 5,000 feet in Pleistocene time.

5. The folded strata of the City Hills in Los Angeles are largely made up of Pliocene strata and hence the age of the folding is post-Pliocene, or Pleistocene. A typical fold of Pliocene strata may be seen along Alvarado street on either side of First street in Los Angeles. Parts of folds can be viewed in exposures on Fifth street opposite the entrance of the Public Library, at First and Hill streets, and elsewhere. The strata at the Library site contains fossils of latest Pliocene (Saugus) Age, as has been determined by others. Hence we must conclude that the miniature

mountains of which these folds are a part were made in some early stage of the Pleistocene epoch. The facts concerning the origin of the Dominguez Range in the latter half of the Pleistocene time have been given on a previous page.

There were several periods of movement in Pleistocene time, but I have not as yet been able to fully consider their definition and classification. This will undoubtedly be undertaken by future students.

FAULT MOVEMENTS OF RECENT TIMES

Notwithstanding the fact that the great movements took place in Pleistocene time, small fault displacements of comparatively recent geologic age may be seen at several localities in Southern California and our occasional earthquakes testify that movements may still sometimes take place along them. These are observable as subparallel, rectilinear grooves in scarps across some of the hills of folded structure and alluvial fans, and their courses are sometimes occupied by modern and but slightly indented drainages. Grooves of this type may be seen east of the summit valley on the east slope of the Baldwin Hills, when observed in the proper light, and on the south side of Dominguez Hill. Their general direction is northwesterly and parallel to the trend of the range.

Recent fault phenomena are also shown in the old talus fans along the southwest front of the San Bernardino Range, and along the southwest scarp line of the Badlands Range.

Noble says that some of the recent scarps developed along the San Andreas Fault along the north side of the San Gabriel Range may date from the Fort

Tejon earthquake of 1857 and cites examples of the displacement of the drainage as it crosses the San Andreas Rift southwest of Cajon Pass.

These recent movements are trivial in comparison to the greater ones of the several epochs of the Pleistocene and, in my opinion, are but the surviving, after-effects thereof. It is a grave mistake to believe that the movements are as active now as they were in the past epochs when the rhythm of the movements were at their apogee.

THIS EXPLAINS SOUTHERN CALIFORNIA

The broad deduction from this story of the faulting is that most of the great physiographic phenomena of Southern California were made by fault block movements and that most of it took place during the great glacial epochs of Pleistocene time. The importance of this conclusion lies in the fact that if the great movements took place in that epoch, they are largely events of the past and we need no longer look upon them with fear, even if slight and expiring after-effects are manifest now and then along a very few of the many fault lines.

Finally, it is to the individuality, modernity and picturesque aspects of these striking master fault lines that Southern California owes its beauties of scenery and salubrity of climate, which are so attractively different from those of other portions of the United States.

In fact, the review herein given of the great fault movements and events that have taken place in Southern California during the Pleistocene epochs contain a satisfactory and complete answer to the earlier question: "Why Southern California?"

GIGANTIC PEAKS SURMOUNTING SAN BERNARDINO FAULT BLOCK
San Andreas and Mill Creek Faults in Middle Ground

PART SEVEN

SUMMARY OF CONCLUSIONS

In concluding this report a brief summary of the premises upon which rests my refutation of earthquake predictions for Los Angeles is in order. The accumulative weight of data substantiates beyond a doubt my deduction that Los Angeles is in no danger of a great earthquake disaster.

Following is a short statement of each step in the progress of this report:

Southern California is not Northern California and the geologic conditions of the two regions are different. Consequently, their seismologic behavior is not the same.

Southern California is a part of a west-American region of mild seismicity and no evidence can be gathered from accurate historic data or from the accounts of the oldest inhabitants that any earthquakes of great intensity have taken place at Los Angeles within historic times.

No proof has been presented of the presence here of the dangerous type of horizontal movements that occurred along the San Andreas Rift at San Francisco or of the transverse stresses that affected the Santa Barbara district.

The City of Los Angeles is remotely situated from the three lines of maximum seismicity in California,

San Andreas, Santa Ynez and San Jacinto Rifts. The City of Los Angeles is also at a sufficiently safe distance from the immediate seaboard and the great abysmal escarpment of the continental shelf to give us reasonable assurance against shocks from sea-marginal slipping.

Even though a master shock should take place along the south end of the San Andreas line of seismicity in Southern California there is no reason for asserting that Los Angeles would be seriously affected by it inasmuch as that fault does not come closer than thirty miles of the city. The average distance of Los Angeles from the path of this fault across Southern California is far greater than that amount. In other words, Los Angeles is sufficiently remote from this dangerous line of seismicity and horizontal movement to discredit the belief that the city is apt to suffer serious damage from it.

The Pacific side of California is but a small part of a greater Pacific border-line of seismicity many thousands of miles in length whose trace is sometimes in the ocean and sometimes on the land, and it is utterly impossible to predict where the greatest strains are along its length or where and when the next great shock or release will occur. Inasmuch as Southern California occupies but a fractional part of this greater line of seismicity, it likewise follows that the theory of alterations of severe seismic occurrence between Northern and Southern California, as advanced by Dr. Willis, has no foundation.

This theory of alternations has been disproved by the fact that three great releases have taken place in the north in the latter part of 1927 since the predic-

tion was made that the next shock would take place in Southern California, and, inferentially, at Los Angeles. One occurred in the sea off Alaska and two in Northern California. One of the latter was along the northern section of the San Andreas Rift in the Cholume Valley of San Benito County, and the other was along the Santa Ynez Rift, near Lompoc. All of these were shocks of relatively great severity and of the kind predicted to next occur in Southern California. Each was far north of Los Angeles.

The records of seismic disturbances that have taken place in Southern California in times past are incomplete and unsatisfactory, inasmuch as they omit on the one hand the mention of many shocks that have taken place and on the other hand greatly exaggerate the intensities of those that have taken place. They are certainly not sufficient to permit deductions, as have been attempted, concerning periodicity or future severity.

The geology of Southern California shows that the great stresses and strain of the movements have been largely relieved in past times. There is no scientific reason for the anticipation of greater shocks in the future than have occurred within the memory of man.

Southern California is a region in which the fractures are broadly distributed, so that intense accumulations and releases of strain are not so strongly probable as where the fractures are closely spaced, as along the Northern California coast. Likewise, the region is one where long accumulations of strain are probably prevented by frequent, slight releases.

Without admitting that any fault line is ever a dead one, I have shown that most of the great

MOUNT WHITNEY
The Altitudinal Climax of the Great Sierra Nevada Fault (Auto Club Photo)

fault lines of Southern California, which some seismologists look upon as probable sites of future movement, are largely things of past geologic time. It is probable that progress towards seismic stability has progressed much farther in Southern California than in the northern part of the state.

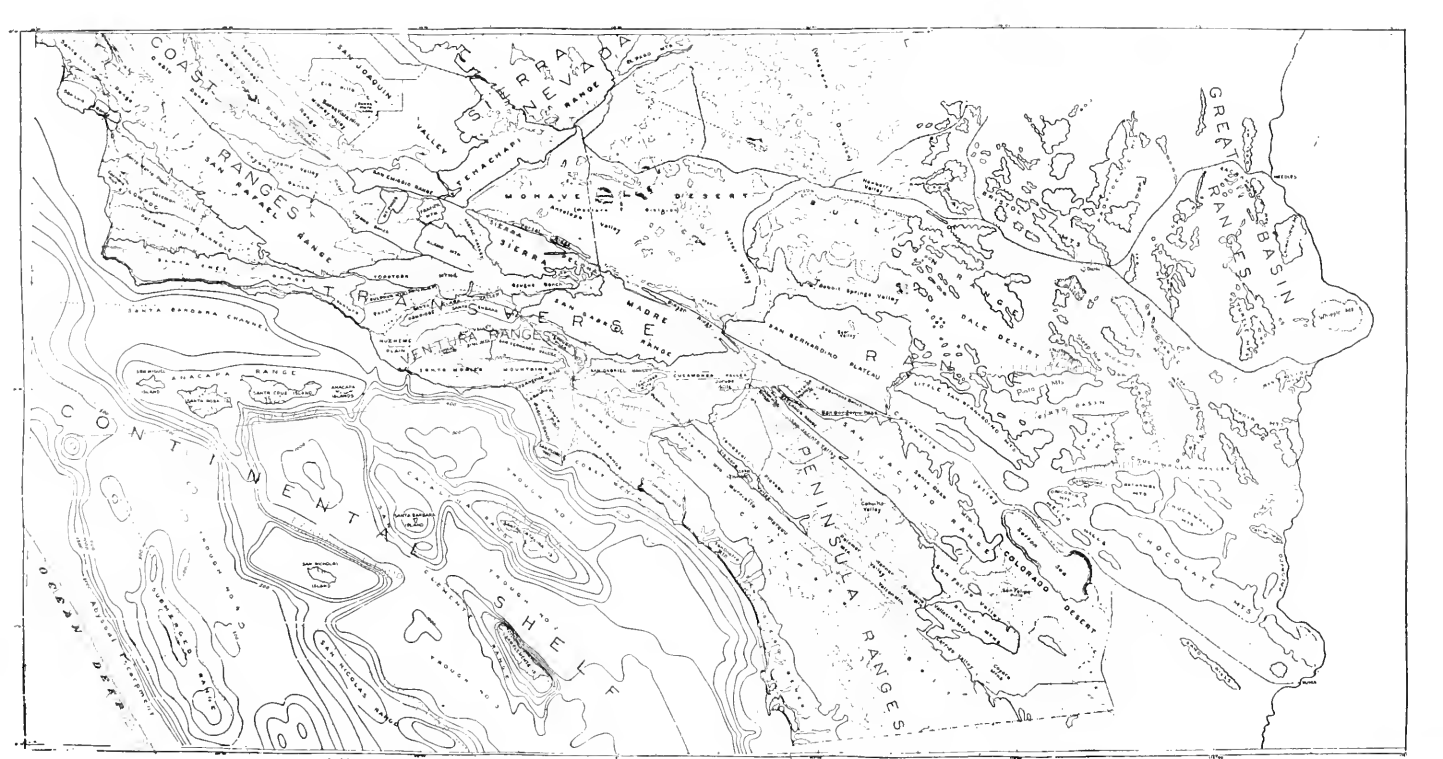
All of the few buildings hitherto injured by shocks in Southern California were structurally weak and condemable. Experiences of the past show that no moderately, well-constructed buildings has ever been destroyed by earthquakes in Southern California.

Many of the great geologists and seismologists are on record in opposition to Dr. Willis' conclusions that times and severities of earthquakes can be predicted. The Dominguez fault is the only allegedly dangerous one at Los Angeles. The authorities of the University of California at Los Angeles, by permitting the new buildings at Westwood to be built almost astride of this line have shown their lack of fear of harm from it.

If the risks at San Francisco and Santa Barbara are to be rated high because these cities are located near lines of more active seismicity, then the risk at Los Angeles, situated farther from such lines, should not be as much. Dr. Willis himself has stated that the danger is practically eliminated at a distance of ten miles from one side of the rift, and the experience at San Francisco and Santa Barbara have shown this fact to be true. The City of Los Angeles is at least thirty miles away from the nearest of them.

I have shown that the data upon which Dr. Willis has created his theories that "we are to have a dangerous earthquake in Southern California at an early

date" were based upon certain, alleged earth movements of the Pacific side of California along the San Andreas Rift which never took place. I have shown that the Coast Survey has cancelled and withdrawn its previous deductions. This being true, the very foundation of the prophecies has collapsed and there is no longer a reason for entertaining the fears of earthquakes in California which their untimely and unfortunate predictions aroused.


COAST RANGES
SAN RAFAEL RANGE
SAN JOAQUIN VALLEY
TEHACHAPI RANGE
SIERRA NEVADA
MOJAVE DESERT
GREAT BASIN RANGES
SIERRA MADRE
SAN BERNARDINO MTS
SAN BERNARDINO PLATEAU
SAN JACINTO MTS
DALE DESERT
COLORADO DESERT
PENINSULA RANGES
CHOCOLATE MTS
TRANSVERSE RANGES
SANTA BARBARA CHANNEL
SANTA MONICA MTS
SAN GABRIEL MTS
SAN FERNANDO VALLEY
SAN GABRIEL VALLEY
SAN GABRIEL MOUNTAINS
SAN GABRIEL RIVER
SAN GABRIEL PEAK
SAN GABRIEL CANYON
SAN GABRIEL RESERVOIR
SAN GABRIEL WASH
SAN GABRIEL PASS
SAN GABRIEL BOULEVARD
SAN GABRIEL
SAN GABRIEL RIVER

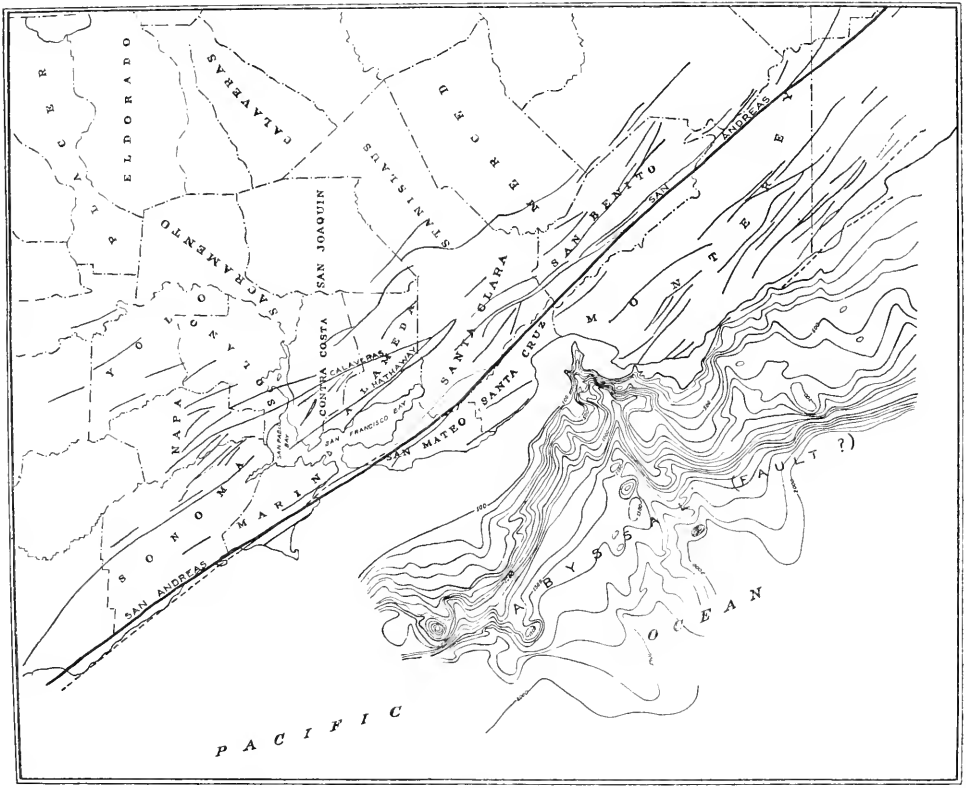


PLATE III. SAN ANDREAS AND OTHER RIFTS OF NORTHERN CALIFORNIA

EARTHQUAKE INVESTIGATION
COMMISSION

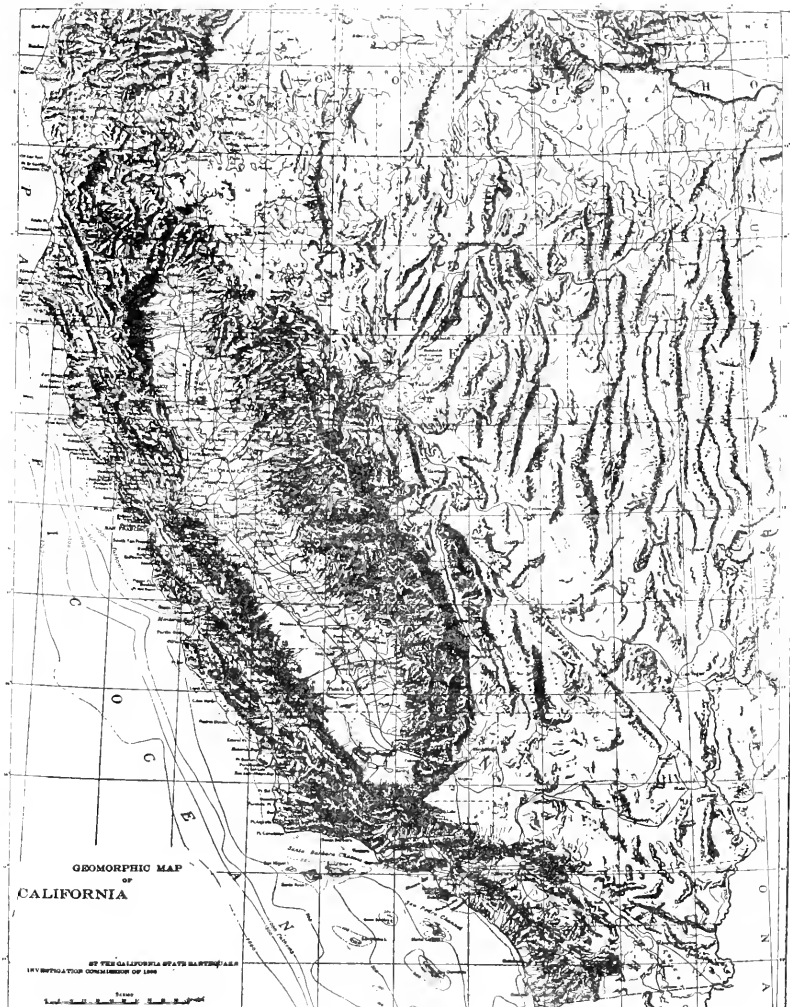


PLATE IV. GEOMORPHIC MAP OF CALIFORNIA

Dr. Hill Has Had One of the Most Distinguished Careers in American Science

He is an author with over 200 titles to his credit. He has been a member of practically every learned society covering his field of activity, among which may be mentioned: Medalist, Geologique Societe de France; Amer. Assoc. for the Adv. of Science; N. Y. Acad. of Sci.; Wash. Acad. of Sci.; Geographical Soc.; Amer. Geographical Soc.; Southwestern Geological Soc.; Branner Geological Soc.; Geological Soc. of Amer.; Natnl. Geographical Society; Washington Philosophical Soc.; Seismological Soc. of Petroleum Geologists (honorary membership bestowed 1926, "in consideration of his valuable contributions to the science of petroleum geology"); etc. His career with the U. S. Geological Survey extended from 1885 to 1925, during which period he was advanced to the positions of executive Officer and Senior Geologist, being honorably retired from the latter position.

Tributes to Dr. Hill's work:

J. B. Lippincott: "Dr. Hill was definitely assigned by the U. S. Geological Survey to special studies for it in Southern California between 1913 and 1917 and he has continued these studies with some interruptions for a period of fifteen years. He has devoted his time particularly to investigations of the fault lines and earth movements that have occurred in the geologic past in this section, and is undoubtedly the best-posted and highest authority that we now have on this subject."

George Otis Smith, Director U. S. Geological Survey: "Your work on the geology of Texas . . . is the foundation on which rests the results obtained . . . by investigators who have worked on that general area."

Faculty of the University of Texas: "You laid a foundation in Texas geology on which those of us who are now working in the State are striving to build. Your name and your publications will remain so long as the science of geology continues."

Bulletin of the Geological Society of America: "He was associated with Alex. Agassiz in explorations of Central Amer. and the West Indies. . . . His contributions to the geology of Mexico, Panama, Costa Rico and the West Indies were important. In fact, wherever he went he made valuable contributions to the fund of geologic information. He is perhaps the first reconnaissance geologist of his day."

Oklahoma Geological Survey: "You have added to our store of knowledge, until now for many years you have been regarded as the world's greatest authority on this subject."

Dr. T. W. Vaughan: "Hlis work constitutes one of the greatest single contributions to knowledge of the Cretaceous of the enormous interior region of the U. S. . . He broke down a dam which had held back the knowledge of the geology of a large part of the continents of both North and South America. . . . Hill's work constitutes one of the most important individual records in the geology of this country. All of us should be proud of it."

Chas N. Gould: "Dr. Hill's work on the geology of the southwest was basal, fundamental, and will stand the test of centuries."

T. C. Chamberlin of Chicago University: "Paper on the Comanchean that has become one of the guideposts of our science."

Douglas Johnson of Columbia: "I belong to that very large number who have been your disciples. . . . very high opinion of which he has of your epoch-making contributions to American geology"

P. S. Smith, Acting Director U. S. Geological Survey: "He is one of the most able of American geologists, has an enviable national reputation and has contributed greatly to the foundations on which geologic science rests."

David White, National Research Council: "Your work has stood the test and is still the standard."